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THE THOMAS YOUNG ORATION

YOUNG'S THEORY OF COLOUR VISION (1801–1931)

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I REGARD it as a great honour to have been asked to deliver the Thomas Young Oration of the Optical Society. Two chief reasons prompted me to accept the invitation. First and foremost was the desire to emphasise the importance of biological factors in all optical problems. In no branch of optics is the necessity for such a liaison between physiology and psychology on the one hand, and physics on the other, better exemplified than in the problems of Colour Vision and colour discrimination. And that brings me to my second reason, viz. the fact that none of the previous orators has dealt with the Young Theory of Colour Vision. This is the more remarkable in that Thomas Young is probably better known as the founder of a theory of colour vision than for any other part of his work. This fact we may attribute chiefly to the service—or disservice—of violent polemics! For, as a matter of fact, Young's contributions to the theory of colour vision are limited to two or three short paragraphs in his voluminous writings, and there is no evidence that he attached very much importance to them himself. And, indeed, previous orators have been right in attaching greater significance to other parts of his work. Greater, for example, was his work on interference of light, with the beautiful evidence it afforded in favour of the wave-theory. Greater too, perhaps, in a totally different field was his work on Egyptology. In both of these spheres he was unlucky during his life-time, for it was not until Fresnel's experiments and Arago's advocacy of the wave-theory that his work obtained the recognition that was its due; and in Egyptology he has never received it even now, in spite of the opportunity afforded by a Champollion centenary for British Egyptologists to assert his claims. But I agree myself with Tscherning, that Young's greatest and most original contributions to science are contained in his paper on "The Mechanism of the Eye" (*Phil. Trans.* **92** 1801). In that masterly monograph he measured the length and other physical constants of his own eye, the index of refraction of the crystalline lens, the amplitude of accommodation, chromatic aberration, the so-called angle α, the limits of the field of vision, and astigmatism. In every respect but one—that of the structure and mode of action of the lens in accommodation—his observations have stood the test of time. It is true that as regards his own astigmatism he measured only that due to his lens and failed to discover the much more important corneal astigmatism. It is true, too, that in all his work he seemed to have scarcely any interest at all in its practical applications. It is fortunate for ophthalmology that he was followed by a Donders, who so successfully exploited his work.

Thomas Young, as Tscherning says, was a "veritable pathfinder," and he repeatedly suffered the fate of so many pioneers in that others reaped most of the credit—Champollion for Egyptology, Fresnel for the undulatory theory, Donders for ophthalmology, Helmholtz for the theory of colour vision. Such repeated ill-luck makes one ask if there was any kink in the man himself to conduce to such a result. If one reads his *Life* by Peacock one cannot help feeling that as a youth he must have been rather a prig. For example, when asked for a specimen of his handwriting he wrote the sentence out in nine different languages. Nothing can excuse the vituperation of Lord Brougham's attack on Young in the *Edinburgh Review*, but its very animus savours rather of personal feeling than just criticism. The *Life* depicts Young as a perfect Admirable Crichton, of impeccable virtue. It does, however, contain one example of his *ipsissima verba*, which, to my unregenerate mind, betokens some consciousness of the frailty of human nature. Young was a physician, though by no means a good one! With a worldly wisdom which throws some light on his character, many of his scientific papers were published anonymously, lest his occupation with other subjects might be prejudicial to his medical practice. He excuses himself as follows (1820): "Certainly if a man that is married to a profession cannot avoid keeping a mistress or two he ought not to be the first to blazon to the world the liberties he takes."

There is of course no doubt that Thomas Young was primarily a physicist. There is astonishingly little evidence of his biological training in his work, and his contributions to medicine are entirely negligible. Such evidence as is to be found is contained in his theory of Colour Vision. As Clerk Maxwell says (*Scientific Papers*, **2** 1890 (267)): "It seems almost a truism to say that colour is a sensation, and yet Young, by honestly recognising this elementary truth, established the first consistent theory of colour. So far as I know, Thomas Young was the first who, starting from the well-known fact that there are three primary colours, sought for the explanation of this fact, not in the nature of light, but in the constitution of man."

Young's own statement of the theory is contained in the following quotations:

"Since, for the reason here assigned by Newton, it is probable that the motion of the retina is rather of a vibratory than of an undulatory nature, the frequency of the vibrations must be dependent on the constitution of this substance. Now, as it is almost impossible to conceive each sensitive point of the retina to contain an infinite number of particles, each capable of vibrating in perfect unison with every possible undulation, it becomes necessary to suppose the number limited, for instance, to the three principal colours, red, yellow, and blue, of which the undulations are related in magnitude nearly as the numbers 8, 7 and 6; and that each of the particles is capable of being put in motion less or more forcibly by undulations differing less or more from a perfect unison; for instance, the undulations of green light being nearly in the ratio of 6½, will affect equally the particles in unison with yellow and blue, and produce the same effect as a light composed of those two species; and each sensitive filament of the nerve may consist of three portions, one for each principal colour" (*Phil. Trans.* **92** 1802 (12)).

"In consequence of Dr Wollaston's correction of the description of the prismatic spectrum, compared with these observations, it becomes necessary to modify the supposition that I advanced in the last Bakerian Lecture, respecting the proportions of the sympathetic fibres of the retina; substituting red, green, and violet, for red, yellow, and blue, and the numbers 7, 6, and 5, for 8, 7, and 6" (*Phil. Trans.* **92** 1802 (387)).

His only other statement relating to the theory is contained in a note on a paper by Dalton, "On some facts relating to the vision of colours" (Young, *A Course of Lectures on Natural Philosophy and the Mechanical Arts*, **2** 1807 (315)). Of Dalton's Colour Blindness he says: "It is much more simple to suppose the absence or paralysis of those fibres of the retina which are calculated to perceive red."

The simplest version of the Young theory predicts (1) that colour "sensations" depend upon the activity of three independent physiological "components," and (2) that the relationship between these components and the complex of stimuli is such that, quantitatively, the response of each component is a real linear function of three standard stimuli. It is a theory of physical-physiological parallelism, founded upon the law of colour mixtures that every conceivable light or light mixture gives rise to a sensation which can be accurately matched by the sensation produced by a suitable mixture of only three lights, provided that such lights are chosen that neither one can be matched by any mixture of the other two.

If we proceed to analyse these statements experimentally we find that browns, olive-greens, and greys possessing some coloured hue are exceptions to the law, and are therefore not explained immediately by the three components theory.

The next step is clearly that of determining the relative values of the three component responses to the monochromatic lights of the spectrum. This was first done by Clerk Maxwell, then by König, then by Abney, and recently by Wright. This is the determination of the three so-called "excitation" or "sensation curves."

Clerk Maxwell's curves, and all the innumerable results of colour mixture for purposes of colorimetry, have shown that such curves, with three spectral primaries, involve negative quantities, owing to unsaturation of some spectral hues. Theoretically and from the mathematical and physical point of view this is of no importance. Physiologically and psychologically, however, it suggests the possibility of the existence of colour sensations which are more saturated than those derived from the spectral hues themselves.

We have therefore arrived at two sets of exceptions to the simple theory; and in each case the explanation is physiological or psychological. For browns, though they cannot be obtained by diminution of the intensity of red or orange light, can be obtained by admixture with black; and this can be done physiologically by "blackening" red or orange light by the negative after-image of white light. Similarly for olive-greens and green.

By a similar process of successive contrast or temporal induction the sensation of hues much more saturated than the corresponding spectral hues can be obtained. This effect is naturally most marked in the least saturated part of the spectrum, viz. the yellow and green neighbourhood.

It is obvious, therefore, that there are good physiological grounds for predicating sensations which are more saturated than those of the spectral hues; and we are justified in applying this fact to the theory with a view to eliminating the complication of negative sensations.

The investigations of König could not fail to bring him sooner or later into somewhat violent contact with the Purkinje phenomenon. Unfortunately for the physicist the human eye is an optical instrument endowed with—or from his point of view, cursed by—rapid and extraordinary variations in sensitivity. Its sensitivity varies with the quantity, quality, and duration of its previous stimulation by light. Its sensitivity to light is prodigiously increased by prolonged dark adaptation. Moreover, in this scotopic condition the maximum luminosity of the spectrum is shifted from the yellow of the photopic condition towards the green. In the bright prismatic spectrum of gas light the red (670 mμ) appears about ten times as bright as the blue (480 mμ); on the other hand, the achromatic scotopic value of the red is less than one-sixteenth that of the blue (v. Kries). It is not surprising, therefore, that, with low illuminations and coincident partial dark adaptation, König met with puzzling matches which he called "deviations from Newton's Laws of Colour Mixture." We have learnt a great deal about dark adaptation since König's time, and his deviations are now buried in oblivion. The lesson which they teach, however, is so vital that I wish especially to stress it before this audience. It is this—that physicists cannot afford to ignore the teachings of physiologists. Physicists have been and are often now supercilious of the relatively inexact sciences, such as physiology, medicine, and psychology. Let them ponder upon this indisputable fact—that all their measurements are founded upon their powers of sensory discrimination. They have been let off very lightly for their comparative neglect of this fundamental fact. It is a sheer piece of luck that they quite empirically hit upon the finest of all forms of sensory discrimination, viz. contour discrimination, and applied it in the form of the vernier to their instruments.

The changes produced by dark adaptation and those resulting from successive and simultaneous contrast (temporal and spatial induction) are so great that some knowledge of these biological peculiarities has fixed itself upon colorimetrists and other physicists. There is reason, however, to think that they have still much to learn. I will give you an example. In some recent and admirable work on the redetermination of the sensation curves the observations were made after five minutes' dark adaptation. The assigned object was to eliminate after-images. From the physiological point of view five minutes'—or less—light adaptation would have been preferable. The rise in sensitivity of the visual mechanism is greatest during the first five minutes, and is then in an unstable condition, whereas after suitable light adaptation it is much more stable. On the other hand, *in the absence of dark adaptation*, colour matches which are valid remain valid in spite of previous stimulation of the same area of the retina. Previous stimulation of the retina will alter the appearance of the patches, but the altered patches will still match each other. This is the law of the persistence of optical equations. It is therefore much more important to eliminate dark adaptation than it is to eliminate after-images, though these should as far as possible be made uniform by exposure to a white area of suitable size and intensity of illumination or by the use of light surrounds for the comparison patches.

The stability of a building depends primarily upon the security of its foundations. The foundation of the Three Components Theory of Colour Vision is the colour triangle, which is a geometrical representation of the facts of colour mixture. These facts are founded upon evidence which is indisputably valid; and no theory of colour vision in which they are not specifically recognised is worthy of consideration. A theory, however, like the Three Components Theory, which is definitely founded upon those facts, must stand or fall by its applicability to the explanation of the far wider field of experience which embraces colour vision as a whole. And indeed, that field may be regarded as coterminous with the whole of visual perception; for as Clerk Maxwell said, "All vision is colour vision, for it is only by observing differences of colour that we distinguish the forms of objects."

Moreover, we must not lose sight of the fact that the construction of the colour triangle depends upon colour equations which are satisfied by an infinite number of solutions; and if this provides us with ample choice, the best choice must be determined by general principles and by facts of colour vision not immediately derived from the facts of colour mixture. Of general principles that of Occam's razor, "Entia non multiplicanda sunt præter necessitatem," has obvious application in colour vision, especially in that more than three variables should not be predicated if three will suffice to explain the facts. We may also cull some further words of wisdom from Young himself. "Although the invention of plausible hypotheses, independent of any connection with experimental observations, can be of very little use in the promotion of natural knowledge; yet the discovery of simple and uniform principles, by which a great number of apparently heterogeneous phenomena are reduced to coherent and universal laws, must ever be allowed to be of considerable importance towards the improvement of the human intellect; and in proportion as more and more phenomena are found to agree with any principles that are laid down, those principles must be allowed to acquire a stronger right to exchange the appellation of hypothesis for that of fundamental laws of nature."

I have already criticised the failure of physicists to pay sufficient attention to physiology. *Per contra*, I much doubt if there are many physiologists who really understand the remarkable juggling feats of König, Helmholtz, Abney, and other physicists. The first essential towards clearing the mind in matters of this sort is to separate the plain, straightforward empirical facts from the hypothetical assumptions. The empirical facts of undoubted validity are really limited to the coefficients of three chosen *spectral* colours in each monochromatic wave-length of the spectrum. As already mentioned these invariably lead to negative quantities owing to the incomplete saturation of the spectral lights. This fact is tacitly implied in Newton's and Grassmann's laws, but was first clearly shown in Clerk Maxwell's curves. It is depicted more clearly and accurately in Wright's curves (Fig. 1).

In German nomenclature the three chosen spectral lights are called the Eichlichte or gauging lights, and the coefficients are called the Eichwerte or gauging values. König of course recognised the negative values of some of the coefficients, and—unfortunately without laying much stress upon his procedure—he altered his spectral primaries to three *hypothetical* primaries so as to eliminate the negative quantities. These resulted in his Elementarempfindungen or elementary sensations. Mathematically the transformation is linear and therefore strictly justifiable. Translated physiologically they imply the existence of colour sensations more saturated than those of the spectral colours; and we have already seen that there is evidence in favour of this hypothesis. König, however, went still further. Accepting the suggestion of Young that Dalton's colour blindness was due to absence of the "red" excitation curve, and applying the same principle to the other great class of colour blinds, of whom his colleague Brodhun was an example, he, by further mathematically legitimate linear transformations, altered his curves to three Grundempfindungen or fundamental sensations, with their corresponding still more hypothetical fundamental primaries (Fig. 2). These are purely theoretical "sensations," each of which, in König's own words, corresponds to "a simple (i.e. unanalysable) process in the periphery of the optic nerve." They are the components of König's and Helmholtz's version of the Young-Helmholtz theory.

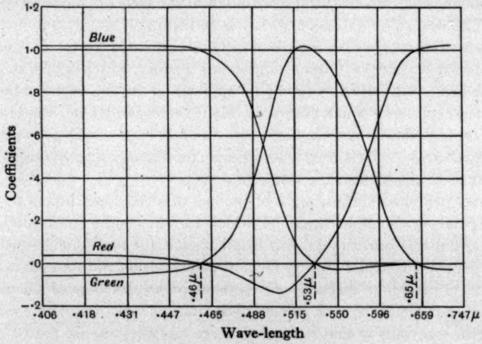

Fig. 1. Coefficients of colour equations (Wright).

The fundamental colours thus arrived at are supersaturated spectral colours corresponding to a purplish red (complementary to 494 mμ, Exner), a green 505 mμ

(508 mμ, Exner), and a blue 470 mμ (475 mμ, Exner). It is a striking fact that these agree with three of the four colours accepted by Hering as best satisfying his theory, viz., purplish red, 495 mμ, and 471 mμ. They also agree with three of the four "invariable" colours derived by Baird from observations on peripheral colour vision, viz., purplish red, 490 mμ, and 460 mμ.

It will be realised that the Three Components Theory accounts well for many of the facts of colour mixture, complementary colours—as shown by the decussations of the curves—and so on. This is to be expected since it is founded upon these facts. But if it is to be regarded as a comprehensive theory of vision it must account for many other phenomena such as the known laws of response of sensory nerves, visual acuity, the luminosity or so-called visibility curve of the spectrum, the saturation of spectral colours, hue discrimination, the facts of simultaneous and successive contrast (spatial and temporal induction), and of colour blindness. It is well known that Helmholtz made strenuous efforts to bring many of these phenomena under the aegis of the theory. His attempts and their mathematical expositions are contained in the second edition of his *Physiological Optics*, and have been admirably reproduced in English by Peddie. The fact that the third German edition reprinted the text of the first and omitted this portion of the second suggests that his efforts have been regarded as less successful than some enthusiasts would admit. They are, however, too important to be ignored, and should be studied as much for the failures which he himself fully recognised as for the fertile suggestions which they contain.

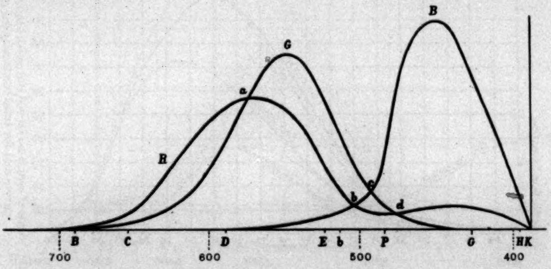

Fig. 2. König and Dieterici's sensation curves, corrected to new determinations of the points of decussation *a*, *b*, *c*, *d* (F. Exner).

More recently Hecht has made an attempt to solve some of these problems, and has certainly succeeded in throwing much light on dark places.

Let us first consider the all-important question of brightness. The photopic luminosity curve, which physicists persist in calling the "visibility" curve, has been the subject of so much accurate investigation by mutually confirmatory methods, that it is now one of the soundest scientific data in the whole realm of vision. It has the form of a frequency curve, with maximum luminosity at 550 mμ on the equal energy scale. It is obvious that this curve cannot be immediately derived from the sensation curves of König, Abney, or Wright (Fig. 3). This is not surprising, since the ordinary equal-area curves expressly separate the two variables, luminosity and colour.

In the general equation

$$C = \alpha R + \beta G + \gamma B$$

α, β, and γ are coefficients representing the proportions of red, green, and blue respectively in the colour. If α, β, and γ are all increased in the same ratio the colour is unchanged, but its intensity is increased. It is therefore legitimate arbitrarily to make $\alpha + \beta + \gamma = 1$, in which case the amount of colour represented by the equation is one trichromatic unit, and is susceptible to ordinary arithmetical laws. In the equal-area curves equal amounts of the three primaries produce the sensation of the white light of the unanalysed spectrum. Abney first, and subsequently Ives, Exner, and Judd, calculated the values of relative luminosities of the units for these curves. Ives's values for the König curves (reduced to equal energy spectrum) are

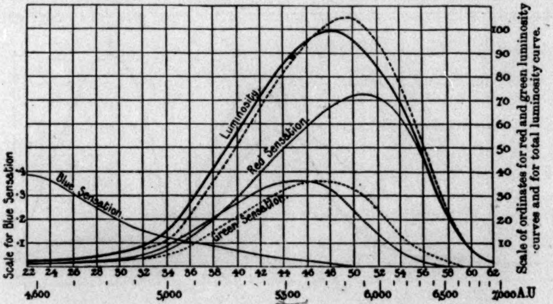

Fig. 3. Normal sensation curves in terms of luminosity (Abney and Watson).

$$L_R = 0{\cdot}568; \quad L_G = 0{\cdot}426; \quad L_B = 0{\cdot}006.$$

Judd's values for the American Optical Society curves and Gibson and Tyndall's luminosity curve are

$$L_R = 0{\cdot}435; \quad L_G = 0{\cdot}547; \quad L_B = 0{\cdot}015.$$

Hence the luminosity of the sensation represented by $\alpha R + \beta G + \gamma B$ is proportional to $\alpha L_R + \beta L_G + \gamma L_B$.

From this, or from a comparison of the sensation curves and the luminosity curve, we see that half the total amount of blue sensation stimulated by white light is due to radiation of wave-lengths less than 450 mμ. Hence the contribution of the violet end of the spectrum to colour quality is enormous, whilst its contribution to luminosity is minute.

These facts of colour and brightness are very difficult to correlate with the Three Components Theory. As Hecht has shown, however, a little quite legitimate mathematical jugglery will produce three sensation curves of equal area which are consonant with both sets of facts. Hecht's curves (Fig. 4) resemble frequency curves and differ from each other only in small but important details. In them the ordinates of $R + G + V$ equal the luminosity at the given point and the sums of all the respective ordinates map out the luminosity curve. This of course they do because they were so calculated to do. As regards colour, any hue is determined by the sum of the ordinates of the two primaries which remain over and above three times that of the lowest; for they are equal area curves, and therefore three times the lowest ordinate represents the amount of white (or unsaturation) in the spectral hue. Therefore the colour is given by $R + G - 2V$ from 500 mμ to 700 mμ, and by $G + V - 2R$ from 400 mμ to 500 mμ.

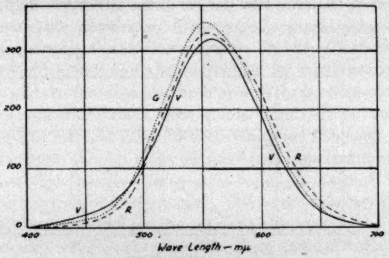

Fig. 4. Hecht's sensation curves.

As Hecht points out, two interesting deductions can be made. First, that even though the brightness of all colours is additive, their colour qualities tend to neutralise each other in certain ways. Second, the white-producing part of most wave-lengths is far greater than the colour-producing part; in other words, the brightness of a colour is very largely determined by its white-producing capacity.

Next, as to hue discrimination in the spectrum. The best experimental work on this subject has been done by König, Steindler, Lloyd Jones, and Laurens and Hamilton. Steindler found four points of maximal discrimination (= minimal threshold)—at 435, 497, 585, and 636 mμ; with three intermediate minima (Fig. 5). The later observers confirm these results, though there is considerable variation in the exact points.

How are these facts to be explained on the Three Components Theory? Helmholtz was the first to suggest the quantitative relationship; viz., that the change in hue in the spectrum is determined by the relative rates of change which the spectral characteristics of the three components undergo. Since it is a question of measurement of different intensities of sensation it is necessary to introduce some form of Fechner's law relating the magnitude of the sensation to the magnitude of the stimulus. The form which Helmholtz adopted, and which permeates the greater part of his mathematical treatment of the theory, is one which involves decidedly doubtful psychological assumptions, e.g. his use of the "self-light" of the retina. Reasoning, however, on these assumptions, Helmholtz arrived theoretically at a differential sensitivity curve which fitted remarkably well the curve derived from König's data. But, in order to do so, he had to juggle again with König's Grundempfindungen in a way which is mathematically impeccable, but which results in curves which do not fit in at all with the facts of colour mixture. Each curve has two maxima, and, as Hecht points out, their only virtue is that they suggest less saturation of the spectral colours than do the ordinary curves.

The deductions from Hecht's curves fit in admirably with Laurens and Hamilton's data, but he himself does not attach much importance to this fact, for they were constructed for that purpose.

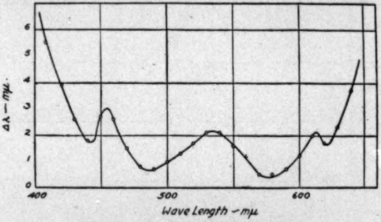

Fig. 5. Laurens and Hamilton's hue discrimination curve with points computed from Hecht's curves.

The most obvious experimental data as to the saturation of spectral colours are those of the complementary colours. It is only rarely that two complementary colours have the same brightness, e.g. 609 mμ and 494 mμ (39·3 : 35·7). In most cases their relative luminosities must be very different in order to make white, e.g. 574 mμ and 472 mμ (69 : 6), 570·5 mμ and 443 mμ (73·2 : 1·8) (Sinden). Helmholtz attributed this fact to the lack of saturation of most of the spectral colours. This suggestion is confirmed by the "least perceptible chromatic purity" (Priest and Brickwedde) or "chromatic threshold with respect to white" (Purdy). Priest and Brickwedde estimated this by taking two photometric fields of equal brightness and adding the spectral colour to one side, keeping the luminosities equal by abstracting the necessary amount of white from the altered field. Much more orange, yellow, or yellow-green had to be added to reach the colour threshold than was the case with red, blue, or violet. Priest and Brickwedde's results show the same relative saturation in the spectrum as Sinden's complementary colour data do, and have the advantage of including also the wave-lengths from 570 mμ to 496 mμ which possess no spectral complementary.

A glance at the equal-area sensation curves of König, Abney, or Wright shows that the maximum of overlap of the curves is found in the yellow-green, and not in the yellow, as should be the case if equal ordinates mean white. Moreover, if the curves are corrected for brightness, the blue curve is practically negligible. Hecht's curves, on the other hand, fulfil the requirements well.

It would therefore appear that there is much to be said in favour of Hecht's curves. They have, however, been submitted to serious criticism by Judd, and found wanting, since they are not an accurate linear homogeneous transformation of the Optical Society of America's standard sensation curves.

Does colour-blindness support the Young theory? Dalton, the contemporary of Young, may be regarded as initiating the scientific study of colour-blindness. Young, as already mentioned, in what is little more than an *obiter dictum*, suggested that the absence of the red component would explain the anomalies of Dalton's vision. In 1837 Seebeck discovered a group of colour-blinds resembling Dalton in confusing reds and greens, but differing markedly in the exact nature of their mistakes. I think that the accumulated knowledge of later years has confirmed to the unbiassed mind the prevalence of these two types of colour-blindness, now generally known as protanopes and deuteranopes. In 1860 Clerk Maxwell showed that a protanope could match any spectral colour by combinations of only two spectral primaries, and the same has also been proved for pronounced deuteranopes. If we call normal people trichromats, these colour-blinds are dichromats. Seebeck also showed that colour matches valid for trichromats are also valid for dichromats. It was further proved that there is a narrow band in the spectrum which to dichromats matches white: this is called the neutral band. It is situated about 500 mμ for protanopes, and 515 mμ for deuteranopes. The complementary purples to these points also naturally match white for the respective groups.

These facts strongly support the view that these cases of colour-blindness are reduction forms of normal colour vision; i.e. the subjects are deficient in some form of sensitivity which the normal possesses, and have no new form of sensitivity. This deduction agrees with Young's explanation of the protanope, and suggests the absence of the green curve to explain the deuteranope. Theoretically another group may be hypothecated in whom the violet curve is absent. The discovery of rare cases of this type—tritanopes—strongly supports the theory. On this theory the neutral points are excellently explained by the point of decussation of the two remaining curves. Helmholtz worked out the theory mathematically and gave it his blessing.

In Helmholtz's scheme all three sensation curves extend to the limits of the spectrum. König's measurements soon showed that this was not true. Indeed the ordinary spectral curve is a straight line from 550 mμ to the red end of the spectrum, if dark adaptation is scrupulously avoided; so that in this range normal vision is dichromatic. If then protanopes lack the red curve the spectrum should appear shortened to them at the red end; and such is the case. König found that the violet curve also could only be traced to 630 mμ: in fact, if dark adaptation is completely eliminated it extends only to 545 mμ (Kohlrausch and Sachs). The green curve extends only from 430 mμ to 660 mμ.

It has been shown of recent years that there are large numbers of people whose colour vision is defective, though they require three spectral primaries to make good matches with spectral colours. These are called anomalous trichromats, and were first accurately investigated by the late Lord Rayleigh (1882). They form two groups, approximating to protanopes and deuteranopes. Theoretically, they may be regarded as having all three curves, but either the red or the green curve has diminished ordinates.

It will be seen therefore, even from this hasty sketch, that many of the facts of partial colour-blindness can be satisfactorily explained by the Three Components Theory. There are, however, many difficulties yet to be surmounted. As with trichromatic vision, so also with dichromatic, the luminosity curves cannot be easily reconciled with the theory, though as Abney has shown the dichromatic luminosity curves fit in well with the trichromatic luminosity curve (Fig. 6). Owing to the negligible contribution of the violet curve to brightness it may be neglected, and it is found that the addition of the ordinates of the two dichromatic curves reproduces the trichromatic curve. Hecht's sensation curves, though they fit in with the trichromatic luminosity curve, and suffice for the deuteranopic curve, fail hopelessly to explain the protanopic luminosity curve.

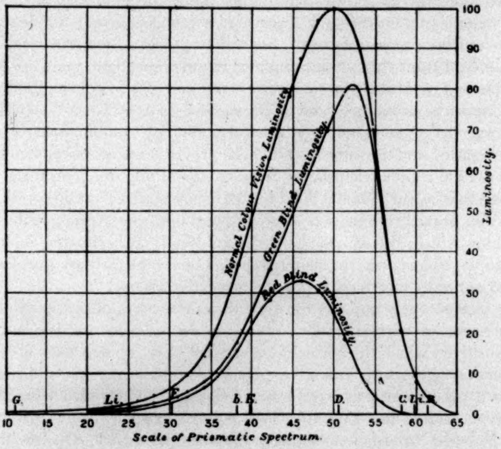

Fig. 6. Photopic luminosity curves of trichromats and dichromats (Abney).

Abney and Watson, whose experience in testing colour-blindness by adequate spectral tests was unrivalled, were content with the theory of reduction forms of the curves for most of the cases of dichromatism and anomalous trichromatism. Some of the latter cases, however, were shown by Abney and Watson to be due to a shift of the green curve, and several other observers, e.g. Tscherning and Larsen, Rönne, Kohlrausch and Sachs, Engelking, are also in favour of even more pronounced shifts. Watson's admirable luminosity measurements by the flicker method go far to explain the vast majority of cases of colour-blindness as reduction forms (Fig. 7). Moreover, in the majority of cases Seebeck's law that colour matches valid for trichromats are also valid for dichromats is true also of anomalous trichromats, and is so far strong evidence in favour of a reduction form. Watson, however, discovered the important fact that the match remained valid for deuteranopes, for example, when excessive amounts of green were added, such as entirely vitiated the match for normal vision. Another unexplained fact has to do with the distribution of types: there are far more deuteranopes and partial deuteranopes than there are protanopes and partial protanopes. Moreover, the protanopes are nearly always bad cases, i.e., almost complete dichromats.

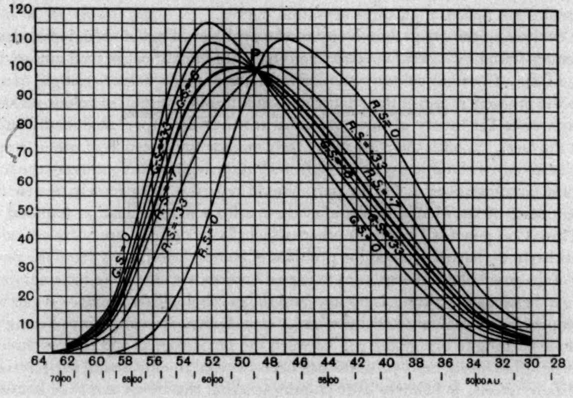

Fig. 7. Luminosity curves of persons having normal and reduced red and green sensations (Watson).

The fact that yellow is psychologically as distinctive a colour quality as red or green or blue, and psychologically shows no evidence of composite character, has always been regarded as a strong argument against the trichromatic theory. To Hecht belongs the honour of proving conclusively that at any rate the sensation yellow produced by the mixture of red and green stimuli has a peripheral mechanism as its basis. He showed that by appropriate means red stimulation of one eye can be binocularly fused with green stimulation of the other, with the result that the yellow sensation is experienced. Much stress has been laid upon the fact that dichromats often describe their sensations either as blue or yellow. Now protanopes clearly should not be able to see yellow. It is to be remembered, however, that the nomenclature of the colour-blind is derived from that of normal people, and is not suited accurately to describe their sensations. Little value is to be attached to reported cases of uniocular colour-blindness; and apart from such cases we have no conception whatever of the real nature of the sensations of the colour-blind. If this argument is valid Fick's explanation is redundant.

There are cases of monochromatic vision in which the individuals match every wave-length with any other, their spectrum differing only in the brightness of its parts. Presumably their vision is similar to that of normal achromatic scotopic vision. There is such an array of facts in favour of this view, and therefore best explained by the Duplicity Theory, that it is unnecessary with Helmholtz and others to predicate a fusion of all three sensation curves.

Considering the great complexity of the problem of colour-blindness, the facts as demonstrated by careful spectroscopic matches are almost as well authenticated as the facts of normal colour vision as subsumed in the colour triangle. In both cases the problem is one of the relationship of luminous stimuli to colour sensations. In both cases the theory of three variables requires no improbable modification to meet the facts. In both there are many facts outside the question of colour response which can only with difficulty be brought within the legitimate confines of the theory. In these circumstances, I, for my part, should regard it as extremely unwise in the present state of knowledge to abandon the methods of examination founded upon the Three Components Theory for others which, in my opinion, are of far less validity.

Hitherto we have discussed the problem of colour vision solely from the point of view of the psychological responses to varied luminous stimuli. We have ignored the long gap between the physical stimulus and the psychological response—a gap which is occupied by physiological events of great complexity. Research since Young's day has done nothing to bridge the gap between the physiological and the psychological response; but considerable progress has been effected in elucidating the physiological response itself. It behoves us to enquire whether this newly acquired knowledge throws any light upon the problem.

The evidence that scotopic vision is initiated by photo-chemical reactions in the visual purple is so overwhelming that we may safely conclude that photopic vision is initiated by allied photochemical changes. I do not propose to bore you with the lucubrations of Lasareff and others on the photochemistry of the retina. It is sufficient for my purpose to adopt the view that light sets up such changes in certain photosensitive substances in the retina as to excite physiological impulses in the nerve cells and conducting nerve fibres.

Now, it has been conclusively proved that nerve impulses, whether in motor or sensory nerves or in the central nervous system, are accompanied by changes in electrical potential in those structures. As early as 1865 it was shown by Holmgren that, if the cornea and optic nerve of a frog's eye are connected by means of non-polarisable electrodes with a galvanometer, light thrown upon the retina causes a deflection of the galvanometer. It has been conclusively proved by many subsequent experimenters that the essential factor in this current is a change of potential in the retina and optic nerve, such that the current flows from the neuro-epithelium towards the optic nerve. It is only of recent years that the use of the capillary electrometer and string galvanometer, especially in conjunction with amplification by thermionic valves, has resulted in reliable curves recording the exact changes of potential under various conditions of stimulation.

The typical curve (Fig. 8) obtained from the vertebrate eye, including man, shows (1) a latent period, (2) a very brief negative phase, succeeded by (3) a rapid steep initial positive phase, which passes into (4) a slight depression, followed by (5) a slowly rising secondary positive phase, which will persist for a long time under continued stimulation. Removal of the light stimulus is followed by (6) a short latent period, and (7) a sharp positive phase, the potential then gradually diminishing to that of the resting state.

Increasing light adaptation diminishes the secondary positive phase in most animals, but in daylight-living birds like the pigeon and fowl the secondary positive phase is present only in the condition of light adaptation (Kohlrausch). There is good evidence to show that the electroretinogram manifests changes which are in very striking accord with most of the laws of visual phenomena. Thus, the absolute threshold is of the same order of energy of stimulus; intermittent stimuli show waves which fuse at the critical frequency of flicker; Talbot's law holds good, and the Weber-Fechner law for 200 to 20,000 lux; the quantity law—intensity × area—holds good; and the Purkinje phenomenon is strikingly manifested.

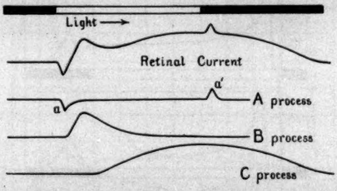

Fig. 8. Electroretinogram with Einthoven's analysis into three processes *A*, *B*, and *C* (Adrian and Matthews).

As might be expected, the responses to monochromatic lights are less striking. Probably most of the animals are partially or completely colour-blind. It is noteworthy that the most definite results have been obtained by Kohlrausch from pigeons, which possess coloured oil globules in their retinae. In them, the shorter the wavelength the stronger the negative phases.

Sachs, with praiseworthy perseverance, has succeeded in confirming many of the facts in man. As regards monochromatic stimuli he could only use low intensities (1–2 lux), so that the results are vitiated by dark adaptation, but the negative phase and marked secondary positive phase are well shown with blue light. Kohlrausch has laid stress on the parallelism of the electroretinogram and recurrent images. With red light Bidwell's "ghost" is absent and the tertiary image is feeble; the negative phase and the secondary positive phase are slight. With blue light the "ghost" is present and the tertiary phase is bright; the negative phase is very deep and the secondary positive phase very well marked.

If these results are confirmed by future work and substantiated it would appear probable that the normal electroretinogram is composite, as suggested by Piper. If so, whether the lower animals possess colour vision such as ours or not, it would seem that the peripheral mechanism, so far as it is revealed by the retinal currents, has all the necessary potentialities. It of course does not follow that the central mechanism is capable of utilising all of them. It is, however, noteworthy that the cephalopod electroretinogram is monophasic.

So far as these results go they tend to show that the fundamental phenomena of vision, including colour vision, already manifest themselves in the retina. In dealing with the visual apparatus the retina is usually spoken of as the "periphery." It is too often forgotten that it is a very different periphery from that of other sense organs. The retina is embryologically and anatomically part of the central nervous system; and it is therefore less surprising that highly complex factors of visual sensations should already be manifested in this structure than it would be to find parallel complexities of touch or taste represented in their end-organs.

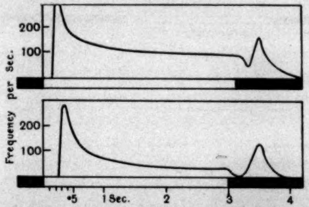

Fig. 9. Frequency of impulses per sec. during and after stimulation of eel's eye. Illumination = 830 metre-candles, disc diameters = 36 and 12·8 mm. (Adrian and Matthews).

If, however, they are thus represented in the retina, how can these qualitative differences be transmitted by the fibres of the optic nerve to higher centres? This brings us to the question of nerve conduction.

The researches of Keith Lucas and Adrian have shown that the electrical changes accompanying the response to adequate stimuli in all motor and sensory nerve fibres have the following characteristics: (1) a diphasic change of potential or a volley of such changes travelling along the fibre away from the site of stimulus; followed by (2) a short refractory period; (3) the "all-or-none" type of response; (4) variations in intensity of the stimulus giving rise to parallel variations in the frequency of the electrical response. The researches of Adrian and Matthews have shown that the same laws hold good for the responses in the optic nerve fibres to light stimuli applied to the retina (Fig. 9). Since the optic nerve is part of the central nervous system we may conclude that they hold good for all conducting paths within the central nervous system.

The almost identical reproduction of the electroretinal curve of the frog's eye with the rhythmic frequency curve of the eel's optic nerve is as striking as the identity of the bleaching curve of visual purple and the achromatic scotopic luminosity curve and the luminosity curve of the totally colour-blind. Similar parallelism is shown between the retinal response to a single strong light stimulus and the frequency curve in the optic nerve in response to a like stimulus. Both curves too are remarkably similar to Broca and Sulzer's luminosity response curve (Figs. 10 and 11).

The most important deduction to be drawn from these electro-physiological researches is that, so far as vision is concerned, many of the characteristic psychological phenomena originate in and are already accurately represented in the peripheral retinal apparatus and retain their identity little modified at any rate as far as the so-called primary optic centres. There is no such evidence of high elaboration in the peripheral end-organs of exteroceptor and proprioceptor nerves. Nor could such be expected; for the retina alone of them has the characteristics of brain matter, containing two neurones in addition to the neuro-epithelial end-organ. The importance of this complexity is indicated, *inter alia*, by the longer latent period of the optic nerve response.

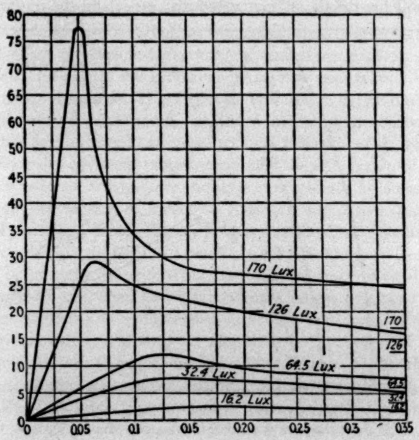

Fig. 10. Curves of response to white light (Broca and Sulzer).

The physiological response gives satisfactory evidence of the mode of transmission of intensity variations along a single fibre, but it has hitherto afforded no evidence of the mode of transmission of qualitative variations, such as colour. No one can doubt that such variations are transmitted, and the only mode which seems possible is by rhythmic groupings of impulses.

The reference already made to Broca and Sulzer's work would naturally lead us on to a consideration of the time relations of stimulus and response. The researches of Piéron, especially those on colour responses to black and white stimuli, as with Benham's top, and those of Frank Allen on inductive effects, as shown on the persistency curves, resulting from previous stimulation of the retina by monochromatic lights, all have a distinct, and on the whole, confirmatory bearing upon Young's theory. Time does not permit me to discuss them in detail. Nor must I embark on the consideration of other visual phenomena. Of these undoubtedly the most important are those of temporal and spatial induction. Recent work by physiologists and psychologists has thrown much light on the phenomena of contrast; e.g. the work of Sherrington and his pupils on motor reflexes, especially the underlying causes of facilitation and inhibition, and the work of Katz, Bühler, Jaensch and others on the constancy of colour perceptions, as well as some of the work of the Gestalt psychologists.

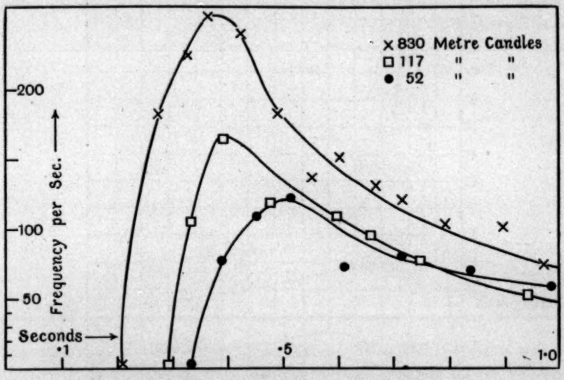

Fig. 11. Evolution of discharge with different intensities of illumination of eel's eye. Disc diameter = 36 mm. (Adrian and Matthews).

I have referred little to the psychological aspects of colour vision, but they cannot be ignored. The psychological response to retinal stimulation by light is not a simple sensation which might be compared to the deflection of a galvanometer. A simple sensation is an abstraction which does not exist in isolated form. Every such response is a perception, resulting from the integration or plurireceptive summation from many stimuli of different intensities, modalities, and qualities impinging upon a receptive area of the brain, whose sensitivity to respond itself depends upon previous stimulation as well as on its own innate capacity. I have elsewhere reviewed the evidence in favour of the view that the rain of sensory impulses undergoes a certain amount of elaboration in lower centres of the brain (the formative zone), and in all probability further elaboration and integration at other levels before finally reaching the cortex cerebri. Not only so, but these lower formative and other zones are affected by backstroke impulses from the cortex. The whole process is in fact very complicated.

Perhaps we may look upon the electrical response to the stretch of a single muscle spindle as the nearest approach to the physical manifestation of a pure sensation. That the responses of the conger eel's optic nerve to a retinal light stimulus are of exactly the same type does not alter the fact that we are now dealing with a much more complex phenomenon. The fact, however, that so many features of the complex electroretinogram are reflected in the periodicity of the electrical response in the optic nerve shows that there is a very high degree of elaboration in the "peripheral" mechanism—in fact, that many of the features of the psychological response are already represented in the peripheral response. This fact reminds one of Sherrington's experiments on binocular flicker: "During binocular regard of an objective image each uniocular mechanism develops independently a sensual image of considerable completeness. The singleness of the binocular perception results from union of these elaborated uniocular sensations. The singleness is therefore the product of a synthesis that works with already elaborated sensations contemporaneously proceeding." Hecht's binocular fusion of red and green to form yellow is of the same nature.

Contrast effects are obviously more complicated than the results of single stimuli. In simultaneous contrast changes are induced in neighbouring areas of the retina, perhaps through the agency of amacrine cells. In successive contrast we must presume that the first or "tuning" stimulus has so altered the sensitivity of the formative zone that the second stimulus produces a different result from what would have occurred on an untuned area. There is much evidence to show that *all* these differences cannot be explained by purely retinal changes produced by the tuning stimulus. There is therefore good reason to believe that many of them occur at higher levels in the brain, and thus far Helmholtz's psychological explanation is justified, although he was wrong in ascribing the effects to an error of judgment.

It must be confessed that we are still far from understanding the complexities of Colour Vision; but some progress has been made, and in my opinion a preponderant part of that progress has resulted from the stimulus of Young's Theory, propounded 130 years ago. As Faraday, the centenary of whose great discovery is being celebrated this year, says: "It is not to be supposed for a moment that speculations of this kind are useless or necessarily hurtful, to natural philosophy. They should ever be held as doubtful, and liable to error or change; but they are wonderful aids in the hands of the experimentalist and mathematician...they lead on, by deduction and correction, to the discovery of new phenomena, and so cause an advance in real physical truth, which, unlike the hypothesis that led to it, becomes fundamental knowledge not subject to change."

I wish to express my thanks to the Cambridge University Press for the loan of the blocks for Figs. 2, 3, 6, 7, and 10, which are taken from the second edition of my book on *Colour Vision*, to the Editors of the *Journal of Physiology* for the loan of the blocks for Figs. 8, 9, and 11, and to the Editor of the *Journal of the Optical Society of America* for permission to copy two illustrations, namely, Figs. 4 and 5. Fig. 1 has been reproduced from Vol. xxx of these *Transactions*.

REFLECTION FACTORS OF PHOTOGRAPHIC PAPERS

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[Communicated by Dr J. W. T. Walsh.]

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ABSTRACT. Reflection factor curves for gaslight photographic papers with matt and glossy surfaces have been obtained for a fixed direction of view of 30°, this direction lying in the plane of incidence. The papers give not only a specular peak, but also a "throwback" peak whose maximum occurs when the directions of incidence and view coincide. The height of the throwback peak is related to the reflection factor of the paper at the angle of the throwback peak by a linear law.

By considering in turn the different components of the photographic paper, the throwback peak has been shown to have its origin in the baryta layer.

The complete reflection factor surfaces for a fixed direction of view of 30° have been built up for two pieces of matt surface paper from the reflection factor curves in different planes.

As various liquid suspensions also give a throwback peak, the peak may have its origin in some kind of scattering effect.

In the experimental work carried out by W. S. Stiles on "Glare and Visibility in Artificially Lighted Streets," contrast discs of photographic paper were used in determining the value of the "difference threshold." It was suggested later that discrepancies which occurred between the values of the threshold computed in the laboratory and measured in the street might be due, in part, to variations in the reflection factor of the photographic paper as the direction of illumination changed. Though it has since been found that these discrepancies can be otherwise explained, the suggestion led the writer to carry out the following investigation.

If light were incident on a perfectly diffuse reflecting surface, then whatever the directional distribution of the incident light, the light reflected from each element of the surface in any given direction would, by definition, be proportional to the cosine of the angle which that direction made with the normal to the surface. The brightness B of such a surface is independent of the direction of view, and is related to the incident illumination I by the equation

$$B = \frac{\rho}{\pi} I,$$

where ρ is a constant for all directions of incidence and view and is called the reflection factor of the surface.

In practice, all known surfaces vary, to a greater or less extent, in brightness according to the direction in which they are viewed, the extreme case being an ideally polished surface which reflects the incident light according to the laws of specular reflection. For a good matt surface, however, the brightness is reasonably constant for quite a large range of angles.

The reflection factor curves for the photographic papers have been obtained by keeping a fixed angle of view of 30° and determining the variation of the quantity $\rho' = B/\cos\theta$ with θ, where θ is the angle which the direction of the incident light makes with the normal to the disc.

The experimental arrangement is shown diagrammatically in Fig. 1. A photographic disc is mounted in the holder *AB* and illuminated with a Pointolite lamp *L* which can be moved round the circumference of a semicircle whose centre is at *O* (the central point of the disc) and whose radius is six feet. Preliminary experiments carried out with 100 W and 30 W diffusing lamps and with the Pointolite, showed that at this distance and with this kind of reflecting surface, each of the illuminating lamps is a sufficient approximation to a point source. The brightness of the surface is measured with a Macbeth illuminometer *M* arranged so that the directions of incidence and view are in a plane perpendicular to the photographic disc.

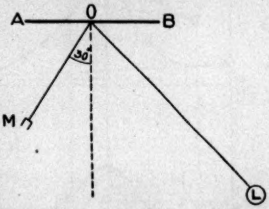


Fig. 1.

The convention will be used that all angles are measured from the normal to the disc and taken as positive when in the quadrant not containing the direction of view. The reflection factor curves for gaslight papers with matt and glossy surfaces are shown in Figs. 2 and 3 respectively. The exposures quoted merely serve to give a rough guide to the blackness of the surfaces.

The nature of the surface of the photographic paper suggests that a maximum in the reflection factor curve will occur at the angle of specular reflection. Actually, as will be seen from Figs. 2 and 3, a second maximum is also obtained at $\theta = -30°$, i.e. when the angles of incidence and view are equal and on the *same* side of the normal to the disc. In practice, it is impossible to reproduce this condition exactly, but observations taken with the illuminating lamp on each side of the illuminometer leave little doubt as to the shape of the curves. For the sake of convenience these two maxima will now be referred to as the specular and throwback peaks. To estimate the height of the peaks, it has been assumed that in the absence of specular reflection and throwback, the reflection factor curves would approximate to the dotted lines in Figs. 2 and 3. The heights of both the specular and throwback peaks decrease as the exposure increases. It will be noticed that the throwback peak has entirely disappeared in the curve corresponding to maximum exposure.

Although the brightness of the glossy-surfaced discs at the angle of specular reflection is very difficult to measure accurately, it is found that for the matt-surfaced discs the difference in height of the specular and throwback peaks is approximately constant for all the curves. This fact suggests that the throwback peak may have its origin in some kind of scattering effect, which, owing to the nature of the photographic paper, can hardly be so simple as the above result would indicate.

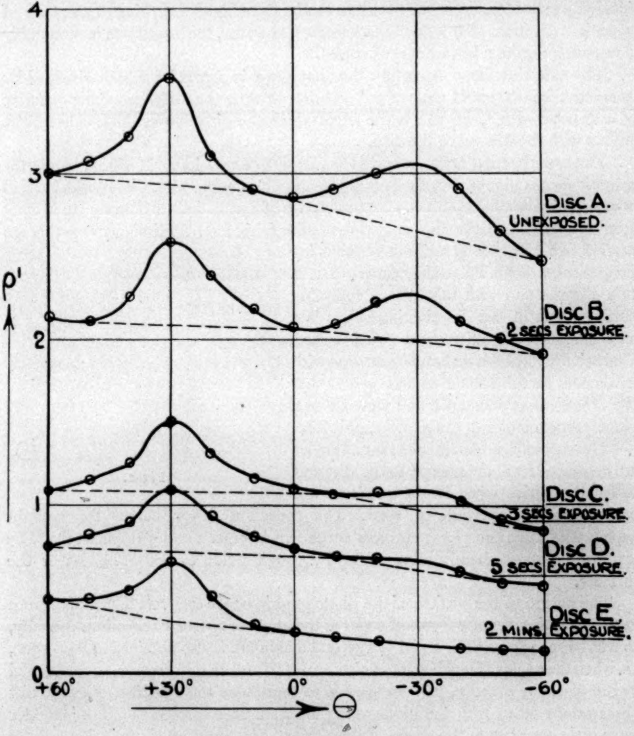


Fig. 2. Matt-surfaced photographic paper.

If ρ_T' is the value of ρ' for a photographic disc at $\theta = -30°$, and h_T is the height of the throwback peak at this angle, then h_T is related to ρ_T' by a linear law (Fig. 4).

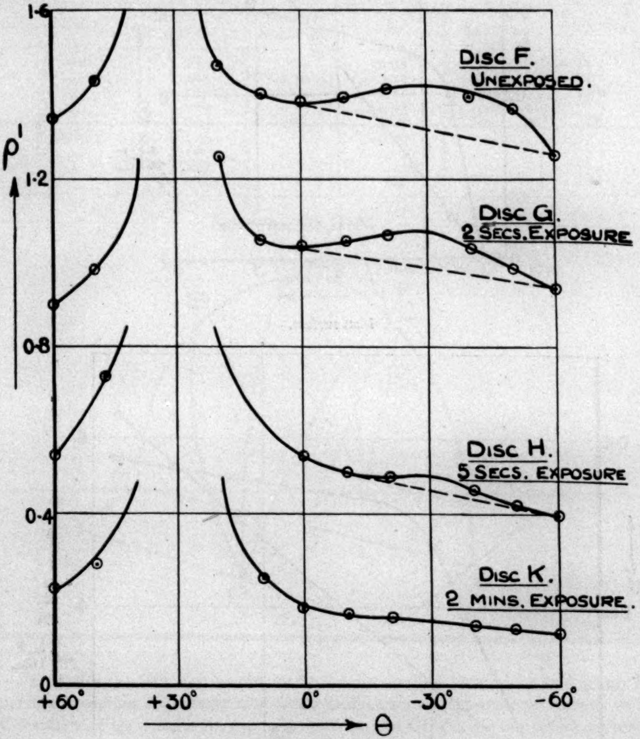
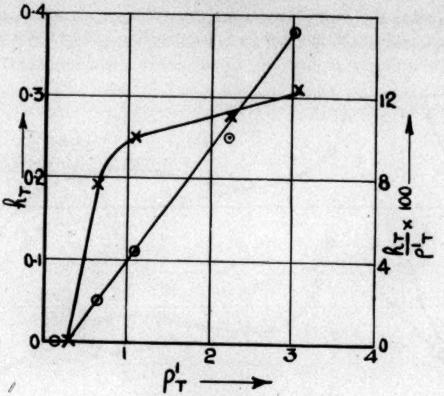
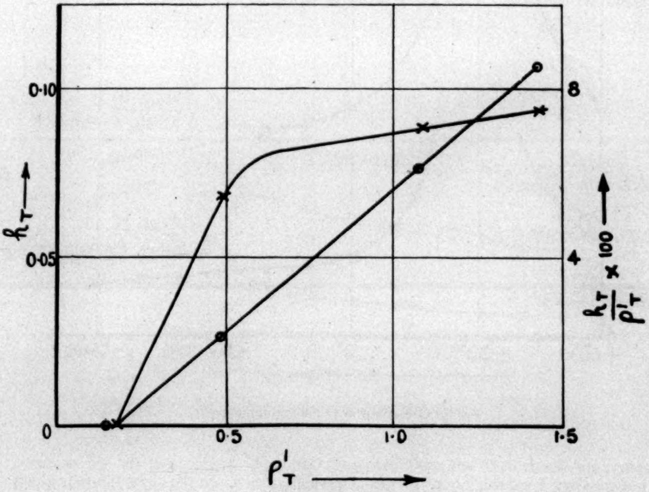


Fig. 3. Glossy-surfaced photographic paper.

It is apparent from this figure that $h_T = 0$ when $\rho_T' > 0$. In the same figure is given the curve of h_T (expressed as a percentage of ρ_T') against ρ_T'. The ratio falls off slowly at first as ρ_T' is decreased, and then drops rapidly away to zero when ρ_T' falls



Matt surface.



Glossy surface.

Fig. 4.

below a certain value. Exactly similar results are obtained for the glossy-surfaced discs.

Table I

Disc	ρ_T'	Specular height (h_S)	h_T	$h_S - h_T$	$\frac{h_T}{\rho_T'} \times 100$
A (matt)	3·05	0·64	0·38	0·26	12·4
B ,,	2·25	0·50	0·25	0·25	11·1
C ,,	1·10	0·42	0·11	0·30	10·0
D ,,	0·65	0·36	0·05	0·31	7·7
E ,,	0·15	0·31	Nil	0·31	Nil
F (glossy)	1·42	—	0·106	—	7·5
G ,,	1·07	—	0·076	—	7·1
H ,,	0·48	—	0·026	—	5·4
K ,,	0·14	—	Nil	—	Nil

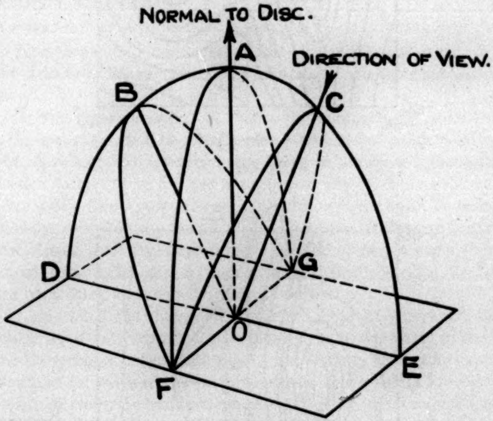


Fig. 5.

The reflection factor curve obtained for a disc in the manner described is only a particular section of the reflection factor surface for a fixed angle of view of 30°. Considering Fig. 5, *OA* is the normal to the disc and *OC* the fixed direction of view. The planes of the semicircles *FBG*, *FAG*, *FCG* are all perpendicular to that of *DAE*. The lines of intersection *OB* and *OC* are each inclined at 30° to *OA*. If the illuminating lamp is moved round each of these semicircles in turn, the four resulting curves will each be a section of the complete reflection factor surface. It is impossible in this paper to consider in detail the method of spherical projection which is used to obtain from these curves the approximate nature of the reflection factor surface in the form of a contour map. The method can, however, be obtained from various mathematical text-books. The reflection factor surfaces for matt-surfaced discs B and E are given in Figs. 6 *a* and 6 *b* (θ and ϕ are the co-ordinates which

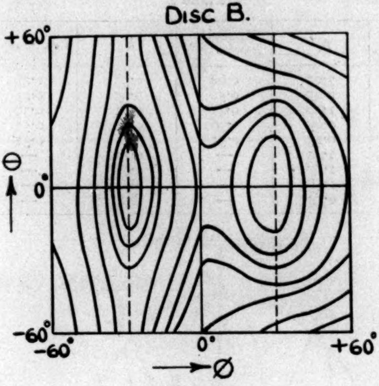


Fig. 6 *a*.

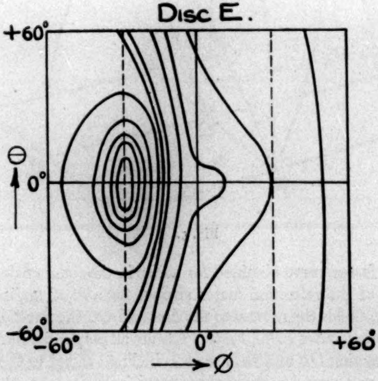


Fig. 6 *b*.

define the direction of illumination. The sections $\phi = 0$ give the curves B and E in Fig. 2). In the former, the contour lines represent increases of 0·1 in ρ' and in the latter increases of 0·05. It would perhaps have been more strictly correct to have given in each case contour lines representing increases of a definite percentage of the mean reflection factor. Since, however, the heights of the specular peaks for discs B and E are in the ratio 5 : 3, whilst their mean reflection factors are in the ratio 7 : 1, this would result in a congestion of contour lines in the neighbourhood of the specular peak in Fig. 6 *b*. As they stand, the figures demonstrate quite well the existence of a throwback peak in one case and not in the other.

The question as to where the throwback peak has its origin leads to a consideration of the constitution of photographic paper. Without going into details as to the preparation of the paper, we may consider it to be composed of three units, namely:

(*a*) A paper base.

(*b*) A suspension of baryta in gelatine which is spread on one side of the base. The quantity of gelatine used is so small, that this layer may be considered as consisting of baryta particles only.

(*c*) A suspension of silver halides in gelatine which is spread over the baryta.

If the paper is exposed, developed and fixed, the only unit which will vary will be (*c*), the density of the metallic silver particles in this layer increasing with the exposure.

Consider first the case of disc A. Since the photographic paper has not been exposed, the upper layer will be gelatine plus a few residual halide or silver particles, and can be reproduced by developing and fixing an unexposed photographic plate. The reflection factor curve for the latter (under the conditions shown in Fig. 1) gives no trace of a throwback peak (Fig. 7), although the specular reflection is increased greatly owing to the presence of the glass base. Reflection factor curves for the raw base (side used for coating) and a sample of baryta paper (baryta coated base) showed that only the baryta paper gave the throwback effect, the height of the throwback peak being approximately 10 per cent. of ρ_T'.

Having associated the throwback effect with the baryta paper, the different photographic discs were reproduced by placing the baryta paper in the holder AB (Fig. 1) and covering it in turn with photographic plates of varying exposures. The results obtained for three of the plates are given in Fig. 7. Allowing for the fact that the specular reflection has been increased owing to the interposition of a glass-air surface, these curves show a striking similarity to curves F, H, and K in the glossy paper series.

The fact that the height of the throwback peak for the different photographic discs decreases as the exposure increases suggests that the action of the silver particles is to exercise a screening effect on the baryta. If ρ_T' is the value of ρ' for a disc when $\theta = -30°$, and ρ_S' and ρ_B' are corresponding quantities for the silver particles and the baryta, it may be derived from a calculation of the screening effect that

$$h_T = K\rho_B' \left\{\frac{\rho_S' - \rho_T'}{\rho_S' - \rho_B'}\right\},$$

K being a constant. This equation shows that h_T is related to ρ_T' by a linear law, and that h_T will become zero when $\rho_T' = \rho_S'$, in confirmation of the experimental results.

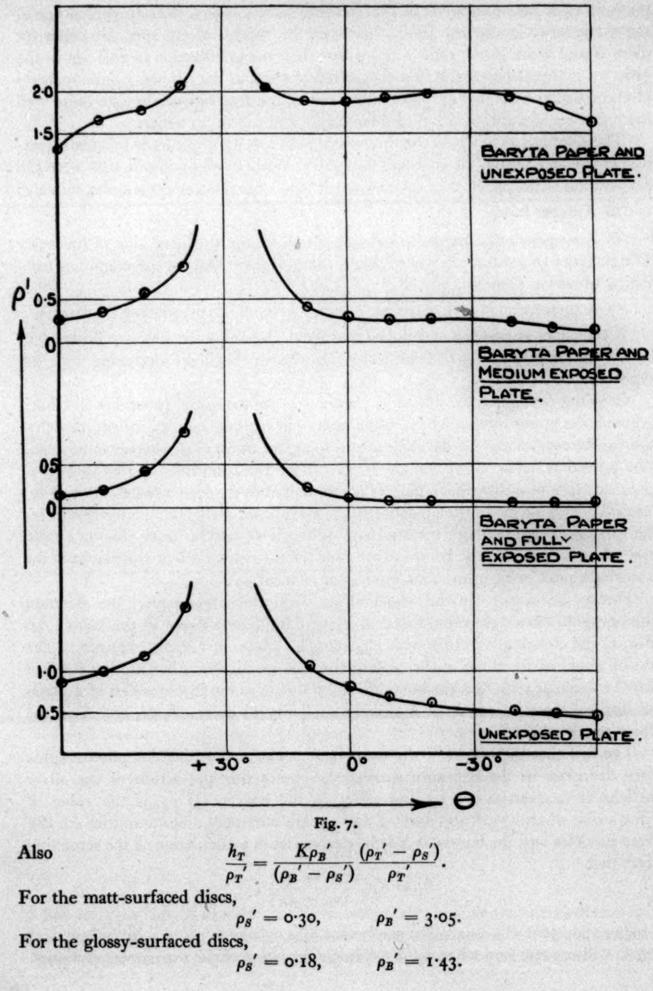


Fig. 7.

Also
$$\frac{h_T}{\rho_T'} = \frac{K\rho_B'}{(\rho_B' - \rho_S')} \frac{(\rho_T' - \rho_S')}{\rho_T'}.$$

For the matt-surfaced discs,
$$\rho_S' = 0{\cdot}30, \qquad \rho_B' = 3{\cdot}05.$$

For the glossy-surfaced discs,
$$\rho_S' = 0{\cdot}18, \qquad \rho_B' = 1{\cdot}43.$$

Using these values, one can calculate what the height of the throwback peak (as a percentage of ρ_T') ought to be for the different photographic discs. A comparison of the calculated and experimental results is given in Table II.

The agreement obtained is certainly within the limits of experimental error.

It was suggested previously that as the difference in height of the throwback and specular peaks was approximately constant for all the matt-surfaced discs, the throwback peak might have its origin in some kind of scattering effect. To test this point, reflection factor curves have been obtained for milk, a sulphur suspension, cod-liver oil emulsion, water, and matt-surfaced opal under the experimental conditions of Fig. 1. The sulphur suspension is obtained by dissolving sulphur in acetone and precipitating it by pouring the solution into water. Milk, sulphur suspension, and cod-liver oil emulsion seem to give the effect quite definitely. It is rather difficult to say anything about the case of water, since such a large depth is necessary before the effect of the containing vessel is cut out entirely. The result shown in Fig. 8 *b* is, however, sufficiently conclusive for one to state that the throwback peak in the

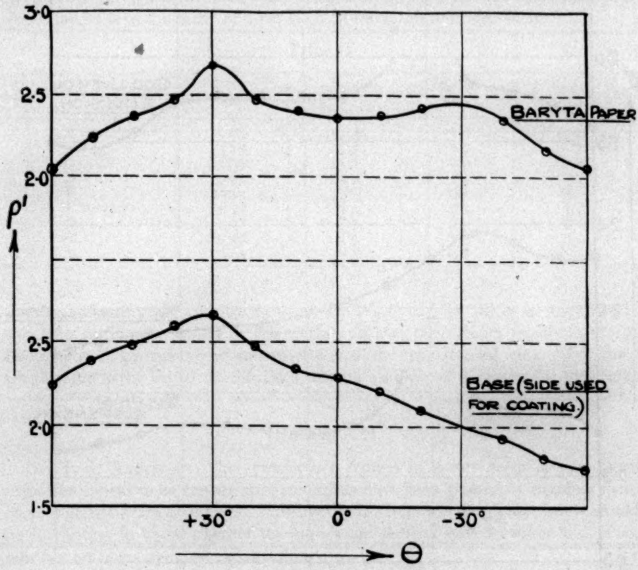


Fig. 8 *a*.

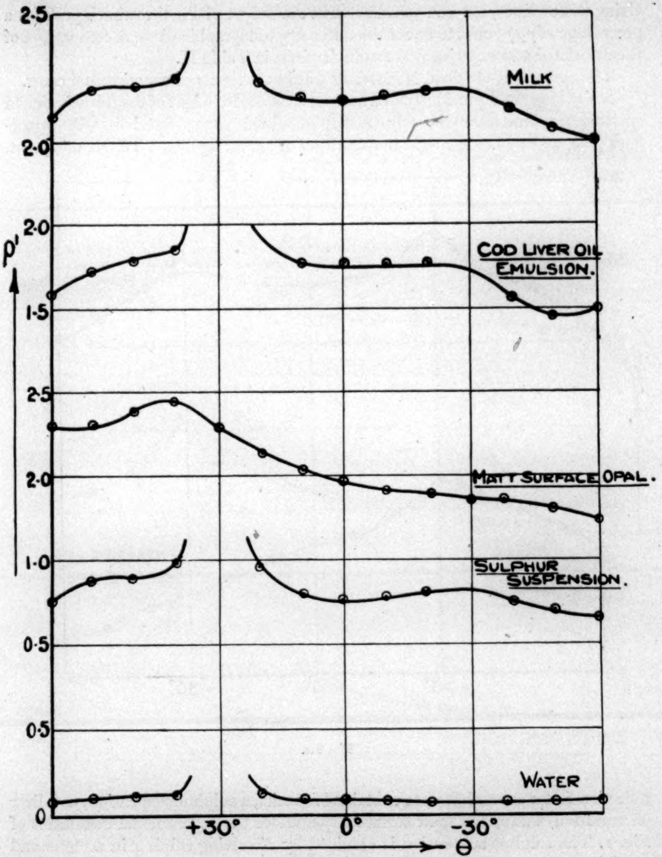


Fig. 8 *b*.

sulphur suspension curve is due to the sulphur particles and not to any back scattering from the water. It is rather surprising that matt-surfaced opal should give practically no trace of a throwback peak in view of the results obtained for other suspensions, since opal glass is known to be a suspension of small crystals in a matrix of different refractive index. It has been suggested that the effect is destroyed by the matting of the surface, and a later curve obtained for flashed opal seemed to confirm this explanation. The flashed opal does give a throwback peak but the peak is extremely flat. It may be that the particles in the opals used were not in the range of particle size which gives a pronounced back scattering effect. A curve for magnesium oxide obtained by J. S. Preston (who used a fixed angle of incidence of 45° and an angle of view which varied in the plane of incidence) gives a throwback peak whose height is of the order of 6 per cent. of the mean reflection factor.

Table II

Disc	ρ_T'	$\dfrac{K\rho_B'}{\rho_B' - \rho_S'}$	h_T/ρ_T' (calc.)	h_T/ρ_T' (exp.)
A (matt)	3·05	13·7	12·3	12·4
B ,,	2·25	13·7	10·7	11·1
C ,,	1·10	13·7	10·0	10·0
D ,,	0·65	13·7	7·4	7·7
E ,,	0·15	13·7	Nil	Nil
F (glossy)	1·42	8·5	7·5	7·5
G ,,	1·07	8·5	7·2	7·1
H ,,	0·48	8·5	5·3	5·4
K ,,	0·14	8·5	Nil	Nil

In conclusion, I should like to thank Dr Walsh and Dr Stiles for suggestions and help during the course of the work, and also the various members of the Photometry Department who undertook part of the experimental work. My thanks are also due to the British Kodak Company for a supply of photographic materials.

DISCUSSION

Dr J. S. Anderson: The interference fringes in prints from interferogram negatives appear to be crisper after the prints have been glossed by pressing them on to a glass surface when wet. Possibly the difference is imaginary, but it would be interesting to know whether the author has noticed such an effect and, if so, whether he can suggest an explanation.

Mr W. Gamble: It is not quite clear what is the purpose of determining these reflection factors, but those who have to copy prints with arc lighting are well aware that the surface of the paper has a considerable influence on the results obtained, and it is found preferable to work from glossy-surfaced prints, which are easily obtained by drying on glass in some such way as Dr Anderson has mentioned. The arc lamps have to be carefully placed so as to avoid surface reflections being recorded on the plate.

Mr M. O. Pelton: I should like to ask Mr Dunbar if there is any information available as to the size of the baryta particles which appear to be the cause of the throwback peak.

Also were the measurements on paper base made in any particular direction? The paper is presumably rolled during manufacture and in consequence probably has different properties in different directions.

Mr Dunbar: I have often noticed the effect to which Dr Anderson refers, and it may be that the effect is not wholly imaginary. The contrast in the picture is due to the diffuse reflection from the baryta and silver particles, but superimposed on this is a semi-diffuse reflection from the pitted gelatine surface. Glazing the print evens out this surface and makes the reflection from it more specular. Provided that the print is not viewed near the angle of specular reflection, the surface reflection will be decreased as a result of glazing, and although the actual contrast in the print may not have changed, yet the partial removal of the surface reflection may make the contrast more easily observable. The effect may also partly be due to refraction at a more even surface.

In reply to Mr Gamble, photographic test discs are used in many branches of photometric work to determine the value of the "brightness difference threshold." The test discs consist, in general, of a small spot on a background of lower reflection factor. One purpose of this paper is to emphasise the fact that considerable error may be involved if the threshold value is deduced from reflection factor differences measured for a particular condition of incidence and view while a different condition is used in the experimental determination of the threshold.

When the existence of the throwback peak was first detected, it seemed possible that its occurrence might be due either, as Mr Pelton suggests, to the form that the paper had assumed during rolling, or to the deviation of the illuminant from a point source. Measurements were made on the photographic paper when reversed in the holder, i.e. rotated through 180°, and no difference in the form of the reflection factor curve was obtained. If the throwback peak were due to a peculiarity of the surface of the paper base, then as the throwback peak has been obtained through the baryta coating, presumably a change in form of the curve, on rotation of the photographic paper, would also have been observed.

Attention has already been drawn to the fact that an interchange of diffusing and Pointolite lamps had no effect on the form of the reflection factor curve.

The size of the baryta particles is of the order of 5μ, although the size may vary considerably in the same emulsion. This is too large for the throwback peak to be due to a true scattering effect.

AN APPLICATION OF THE PHOTO-ELECTRIC CELL TO A COMPARISON OF THE EFFICIENCIES OF PHOTOGRAPHIC SHUTTERS

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MS. received, 4th June, 1931. Read and discussed, 25th June, 1931.

ABSTRACT. The paper describes a method of comparing the efficiencies of shutters, incorporating photo-electric measurements of the total amounts of light passed by the shutters. Details of an application of the method to a new type of shutter are given.

Introduction

The efficiency of a photographic shutter is defined as the ratio of the total amount of light which passes through the shutter to the amount which would have been transmitted if the light had not been obscured by any part of the shutter during the whole period of the exposure. This definition may be expressed mathematically in the following way.

Let q = the rate at which light is transmitted by the shutter,
q_0 = the rate at which light is transmitted without the shutter,
T = the duration of the shutter exposure,
and $Q = \int q\,dt$, $Q_0 = \int q_0\,dt = q_0 T$,

where the period of integration is the total duration of the exposure.

Then the efficiency E by the definition is Q/Q_0

or

$$E = Q/q_0 T \qquad \text{......(1).}$$

If we compare the efficiencies of two shutters with the same illumination the relative efficiency is given by

$$\frac{E_1}{E_2} = \frac{Q_1}{q_0 T_1} \cdot \frac{q_0 T_2}{Q_2} = \frac{Q_1}{Q_2} \cdot \frac{T_2}{T_1} \qquad \text{......(2).}$$

The definition assumes that the lighting is specified. In practice we are interested in the efficiency of the shutter in combination with a given lens, and uniform illumination of the lens is usually assumed. If the lens is given and correct illumination arranged, the efficiencies of two shutters can, by equation (2), be compared if measurements are made of the two ratios Q_1/Q_2 and T_1/T_2. In the method to be described T_1 and T_2 are measured in the manner usually employed at the National Physical Laboratory for determining the speed of a shutter*, and the ratio Q_1/Q_2 is measured by photo-electric means, preliminary experiments made with shutters a few years ago by Dr D. S. Perfect in this laboratory having shown that a photo-electric method could be successfully employed for such measurements.

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* A. Campbell and T. Smith, *Proc. Phys. Soc.* **22** 1907–9 (788); J. S. Anderson, *Trans. Opt Soc.* **22** 1920–21 (161).

Description of Method

The apparatus for making the two measurements is shown diagrammatically in Fig. 1. Light from a 100-watt "Pointolite" lamp *F* is focussed by a lens *G* on a small hole *H* in a plate fixed in the focal plane of the camera *K*. It then passes through the shutter *L*, fills the aperture of the camera lens *M* and emerges from the latter as a parallel beam. By correct adjustment of *F* and *G* this beam can be made sensibly uniform in brightness. It next falls on a partially silvered mirror *N* which divides it into two portions. The transmitted beam is focussed by a lens *O* to form a small image of the illuminated hole *H* on the surface of a drum *E*. A reduced image of the tungsten ball of the "Pointolite" lamp *F* is formed alongside this image by light which has passed through lenses *B* and *D* after reflection at the mirror *A* of a vibration galvanometer in tune with an electrically-maintained tuning-fork. The drum, bearing a piece of bromide paper, is rotated at a convenient speed. When an exposure is made the developed paper shows a black line alongside the time trace. To limit the length of the time trace an auxiliary shutter *C* is placed between lenses *B* and *D*. Its speed is adjusted to be somewhat longer than that of *L*. As a further precaution against the time trace overlapping itself it is advisable to move the drum slowly along its axis during an exposure. If the distance between the two images on the drum is measured when the shutters *L* and *C* are kept open and the mirror *A* is not vibrating, it is easy to pick out from the record the portion of the time trace impressed during the exposure of *L* and it is not therefore necessary for the rotation of the drum to be uniform. The length of the line obtained on the

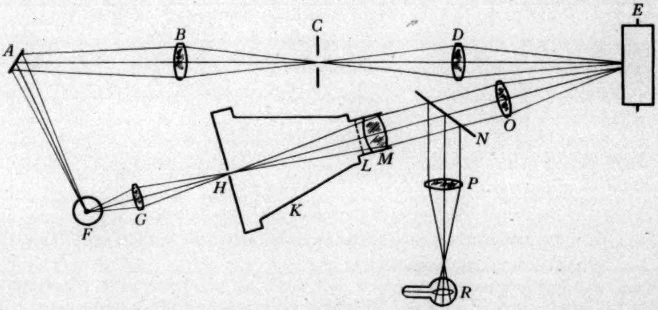

Fig. 1.

record, measured on the scale of the time trace, gives the total time during which light from the hole H passes through some part of the shutter and camera lens system, that is, it gives a measure of T.

A portion of the beam of light emerging from the camera lens M is reflected by the partially silvered mirror N and concentrated on a suitable area of the sensitive surface of the photo-electric cell R by means of the lens P. Thus, while the exposure is being made to determine T, the total quantity of light Q passing through the shutter and camera lens, or rather the definite fraction of this quantity reflected by N, can be recorded photo-electrically.

Let q = the rate at which light falls on the cell,
N = the rate at which electrons are released from the cathode,
N' = the rate at which electrons are collected by the anode,
and V = the total charge acquired by the anode during an exposure.

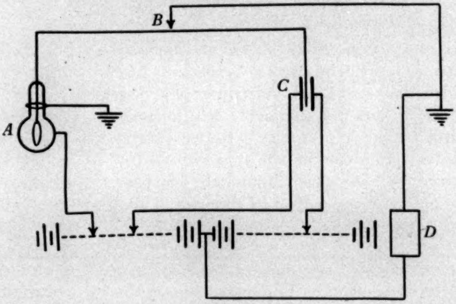

Fig. 2.

Then N is nearly proportional to q and N' is proportional to N. Thus

$$V = k \int q \, dt \qquad \text{......(3)},$$

where k is a constant and the period of integration is the total duration of the exposure. We therefore obtain

$$V = kQ \qquad \text{......(4)}$$

and the ratio Q_1/Q_2 is then given by the ratio of the potentials the insulated anode of the cell acquires, that is, by the ratio of the deflections of the recording instrument to which the anode is connected.

A commonly used type of electrical circuit was employed and is shown in Fig. 2. One terminal of a high tension battery is connected through a safety water-resistance D to earth. A suitable negative potential is applied to the sensitive surface of the cell A, the anode of which is connected through an earthing key B to the needle of a Lindemann electrometer C mounted on the stage of a microscope.

Suitable positive and negative potentials are applied to the two plates of the electrometer respectively. The guard ring of the cell, the box enclosing the cell, the tube used for screening the connection between the cell and the electrometer, and the case of the electrometer are all earthed.

To obtain accurate results it is essential to keep constant the intensity of the light given out by the source. To this end it is advisable to run the "Pointolite" lamp from a battery unless other facilities for controlling the intensity are available.

The method outlined gives only the relative efficiencies of two shutters. Absolute efficiencies can be deduced if comparison with a shutter of known efficiency is included in the experiments. As the efficiency of a focal plane shutter can be determined theoretically from measurements of the width of the opening in the blind, the distance of the blind from the focal plane, and the relative effective aperture of the camera lens, the inclusion of such a shutter in the tests enables absolute efficiencies to be derived.

Application of Method to New Type of Shutter

It may be of some interest to describe the application of this method to a new louvre shutter developed by Messrs Williamson Manufacturing Co., Ltd. The shutter, which is shown in Fig. 3, differs in several respects from the one described before this Society about two years ago[*]. It is designed for use immediately behind the camera lens and not in proximity to the focal plane. The leaves are shorter and fewer in number, and rotate through approximately 90° to the fully open position and then return to the initial closed position. The planes of the leaves in the open position are not quite parallel, but are disposed to allow as much light as possible to reach all parts of the plate. The shutter has three different speeds. It was tested in position in a whole-plate camera fitted with an $f/4{\cdot}5$ lens of focal length 10 inches, and the absolute efficiency was derived by comparison with a focal plane shutter which could be inserted in an improvised box at the back of the camera. The relative efficiency was measured at three points, the centre of the plate and two symmetrically situated points lying on a diagonal of the plate, each distant 10 cm. from the centre. For convenience these may be designated the middle, upper, and lower points. Throughout the test the lens axis was kept horizontal, and the blind of the focal plane shutter moved vertically downwards during exposures. The lens was used at full aperture and the focal plane shutter at the nominal speed of 1/60 second, which corresponded approximately to the slowest speed of the louvre shutter. It was decided that, if the speeds of each shutter were reasonably consistent in successive exposures, it would be more convenient in the first trial of the method to measure T and Q separately and adopt mean values if the variations were sufficiently small. A preliminary investigation showed that with the two shutters in question this method of procedure would be satisfactory.

A metal plate with three small holes corresponding to the middle, upper, and lower points was fitted in the focal plane of the camera and the measurements of T and Q were made for each of the three holes, first with the louvre shutter and then with the focal plane shutter. It was found convenient to have the axis of the beam of light which fell on the recording elements horizontal in each case. As the axis of the camera was horizontal it was necessary to introduce at least one mirror in the system when dealing with the oblique beams from the upper and lower holes. A mirror corresponding to the one marked N in Fig. 1 was therefore used and its position and the height and direction of the camera were adjusted for each beam.

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[*] J. S. Anderson, *Trans. Opt. Soc.* **30** 1928–29 (165).

The photo-electric cell was of the potassium gas-filled type, and it was found that sufficient sensitivity could be obtained when a potential of about − 80 volts was applied to the cell and potentials of about ± 30 volts to the two electrometer plates respectively. By means of a resistance in the arc circuit of the "Pointolite" lamp the intensity of the light was adjusted to secure suitable values of the deflection of the electrometer needle for each of the holes in the plate. In each case the largest deflection was arranged to correspond to about 80 or 90 divisions of the eye-piece scale which contains in all 100 divisions.

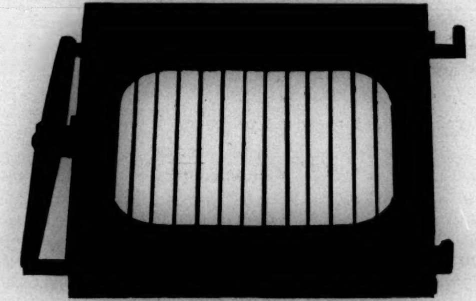

Fig. 3.

The method of measuring the ratio Q_1/Q_2 was as follows. When the louvre shutter was mounted in the camera and set, the cell was uncovered and the earthing key opened; the shutter was then released and the deflection of the electrometer needle noted. This process was repeated several times, the needle being earthed between successive exposures. Readings were next taken for the other two settings of the shutter. After removing this shutter and inserting the focal plane shutter several readings were taken. The louvre shutter was then remounted and a number of readings for each setting taken to make sure that the illumination had not altered. The whole process was then repeated for each of the other two holes. In each case the ratio of the deflections with the louvre and focal plane shutters in position gave the value of Q_1/Q_2 for the particular setting of the louvre shutter and the particular hole used. From the values of this ratio and those of T_1 and T_2 the relative efficiencies of the two shutters were deduced.

It was found that the values of T_1 and T_2 at the different settings did not vary much in successive exposures and that the mean values of the deflections of the electrometer needle were constant to a high degree of accuracy. The values of Q_1/Q_2 were much more consistent in successive exposures than the values of T_1. The explanation of this may be that the differences in the speeds of the louvre shutter for any given setting are chiefly differences in the periods of opening and closing, when only relatively small contributions are made to the total amount of light Q_1.

The efficiency of the focal plane shutter may be deduced theoretically as follows.

Let w = width of opening in blind,
d = distance of blind from focal plane,
a = effective aperture of lens,
f = distance of image plane from back node of lens,
$n = f/a$ = aperture number.

Then the efficiency, expressed as a percentage, is given by

$$E_2 = \frac{100\,wf}{wf + ad} = \frac{100\,wn}{wn + d} \qquad \text{......(5).}$$

Conclusion

The experience gained in carrying out this test leads us to believe that this new method is preferable to the one hitherto employed*. One of the essential conditions for success is rigidity in all parts of the apparatus and especially in the camera, as the shock of releasing the shutter is apt to set up disturbing vibrations.

It would clearly be possible to carry out the tests with the illuminating beam passing in the opposite direction, that is, entering the camera lens as a parallel beam and emerging from one of the holes in the plate. This arrangement was tried but proved to be much less convenient than the one described.

If desired, it would be possible, by the introduction of a suitable optical system, to record the deflection of the electrometer needle on the drum alongside the time trace and speed record.

I wish to express my thanks to Mr A. G. Williams, M.B.E., for his assistance in carrying out the work and to Dr D. S. Perfect for the use of apparatus of his own design developed in the course of his experiments in this laboratory and for frequent assistance during the work. I am indebted to Messrs Williamson for the photograph of the shutter shown in Fig. 3.

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* J. S. Anderson, *Dict. App. Phys.* 4 (673); *Proc. Seventh Intern. Congress of Photography*, 1928 (315).

DISCUSSION

Mr C. N. Williamson: Before I demonstrate the working of my shutter I should like to say how much I appreciate the trouble Dr Anderson has taken over these tests and how valuable the information has been in enabling me to obtain more perfect results. I do not think the National Physical Laboratory is often at a loss to devise satisfactory methods of testing any piece of apparatus, but I do know that louvre shutters are anything but popular. When I presented myself at Dr Anderson's office with this latest model, I knew that I had a stiff problem for him, but I am sure you will agree that it has been tackled in a most ingenious manner.

The idea of a louvre shutter working immediately behind the lens in a camera is by no means new, and is in fact quite popular on the Continent, but my method of supporting and operating the blades I believe to be original and considerably simplifies the mechanism, reduces the power required, and enables high speeds to be obtained with a high overall efficiency.

I have here a rough working model ten times the actual size and this will show the principles on which the shutter operates. In the shutter proper each blade is pivoted separately and formed at one end with a trigger. The triggers are all actuated by projections on a sliding bar so that the blades rotate rapidly through 90° and are held in that position. We have a variety of different ways of moving the bar to and fro to suit the particular work for which the shutter is to be used, but the principle of the blade movement remains substantially the same.

In my earlier experiments I shaped the triggers on the blades in such a way that when in the open position the blades were parallel to the normal light rays from lens to image, but in actual practice I find that little if any advantage is obtained from this procedure.

The stand camera here is the one submitted to Dr Anderson for the tests, but it is now fitted with a later model of louvre shutter in which six blades move in a right-hand and six in a left-hand direction. The actual shutter tested was similar to the one exhibited separately in which all the blades move in the same direction.

You may be interested to know that I have obtained excellent results with the shutter on cameras fitted with very wide-angle lenses, long-focus lenses, and telephoto lenses, both on the ground and in the air, but it is of course in the latter sphere, viz. for air photography where large diameter lenses are necessary, that we find its greatest utility.

Dr Anderson very delicately refrained from mentioning any figures for the efficiency of my shutter, but as Mr Booth has drawn a diagram of the "trace" he obtained on his revolving disc I should like to remove any possibly erroneous impression by stating that the actual figure is in the neighbourhood of 70 per cent.

Mr W. Gamble: The method described shows how great an advance has been made in the testing of photographic shutters since the time when tests of shutter speeds were performed by revolving at a known rate a bicycle wheel, on which a white spot or bright disc was attached, and making an exposure on a photographic plate. On development the spot would form a curve on the image of the rim of the wheel, and the length of this curve, in relation to the circumference of the image of the wheel, divided into the time of revolution gave the speed of the shutter. A bright spot on a pendulum, or a small mirror attached to a quickly revolving pointer in front of a clock face, were also used. Such methods did not afford any indication of the efficiency of the shutter, because they failed to record the time lost in opening and closing the shutter. The author may find it useful to consider the employment of an oscillograph in the electrical circuit, so that the amplitude of the wave-form will be a measure of the performance of the shutter.

Prof. A. F. C. Pollard: The arrangement of parallel shutters in the photographic shutter described by Dr Anderson may cause images of undesirable diffraction effects when distant localised sources of light are photographed. In a letter to *Nature* (1928, p. 246) I pointed out that a narrow obstruction, such as a wire, crossing the aperture of an astronomical telescope object glass will cause a series of spectra to radiate from a star image in opposite directions at right angles to the direction of the wire and that such diffraction effects may be used to measure the relative positions of star images on photographic plates with greater precision than is possible with the diffuse star image itself. In the present arrangement the several parallel leaves will enhance the effect produced by a single obstruction, and I would expect to find images of localised sources of light crossed with rays of diffracted light positioned at right angles to the length of the leaves.

Dr Anderson: I am grateful to Mr Williamson for the kind remarks he has made. The experiment was a very interesting one to carry out and proved to be freer from difficulties than was originally anticipated.

Mr Gamble's suggestion of the employment of an oscillograph in the electrical circuit will be borne in mind should the occasion arise of having to make similar tests in the future.

The point which Prof. Pollard has raised is certainly of importance should there be any localised light sources in the field of view during an exposure, as these would give rise to diffraction effects when the shutter leaves are partially closed. It is conceivable that for certain purposes connected with aerial survey work this might be made use of in the same way as Prof. Pollard has suggested for astronomical work.

REVIEWS

Mesure Optique des Distances et Méthode des Co-ordonnées Polaires. Par R. Bosshardt. Translated from the German into French by Maurice Delessert. Pp. 172; 102 Figs. and 3 Maps. (Geneva: Georg et Cie, 1930.) Price 10 fr.

Switzerland, and the alpine landscape native also to surrounding territories, are naturally difficult to survey by tape or chain and offset. They are often equally unsuitable for the plane table. It is in this region and in the Canadian Rockies that ground phototopography won its place and it is naturally here too that we find the optical measure of distance in its most efficient form. It does not follow that we shall all be wise to try the same methods, but it does follow that it is to Switzerland we must turn for the widest experience of this method.

M. Bosshardt is in the delicate position of the inventor who sets to work to explain not only his own instrument, but his subject and his rivals. He does it well. His main object is to describe those recent telemeters which measure distances (up to four or five hundred feet) with errors of the order of one part in five thousand, or roughly a tenth of that characteristic of the ordinary tachymeter, and in the process he gives an interesting history of the growth of optical distance measurement and of its application (in local systems of polar co-ordinates) to the surveys of townships.

With the tachymeter, its fixed diaphragm hairs or lines, its parallactic angle, its "constant" or its anallactic lens, we are all acquainted. Of little value either to organised survey on a large scale or to the topographical surveyor it has filled a real want for the medium scales, and for the engineering survey of sites, roads, and railways lines. Its worst feature is the "differential refraction" which curves the rays from bottom and top of a vertical staff unequally.

The first step was to adopt a horizontal staff. Even then, as the author points out, lateral refraction may come in, and he quotes a case of appreciable error due to one end of the staff being held near a south-facing masonry wall. On the whole, however, errors are more than halved by this simple measure.

The next step is to add precision of pointing at, and reading from, the staff by substituting a suitable "double image" and a method of coincidence for the old top and bottom readings. The face of the horizontal staff or target (2½–3 metres long) is divided into an upper and a lower half, and on each half is a scale. In the ordinary "field" of theodolite or tachymeter these two scales must appear, as they are, fixed in position with regard to each other. In the Bosshardt, Wild, and some other telemeters the scales are seen separately through the top and bottom halves of the objective. In front of one half is an arrangement of prisms which deflects the image of the corresponding scale, *laterally*, by the parallactic angle (α). The amount it is so displaced depends naturally upon α and upon the distance. When observing on the staff no *exact* coincidence between top and bottom lines or spaces could be made without some final slow motion movement. This is provided by the parallel plate micrometer (to which the Zeiss level has accustomed us). The angular movement of the parallel plate is given, in terms of distance, on the small drum which operates it. Tachymetric distances are not measured in the horizontal plane (as are subtense measurements) and therefore, unless instrumental design automatically corrects, they must be reduced to the horizontal (by the cosine of the angle of elevation).

In the Bosshardt Zeiss instrument the parallactic angle is given by inserting *two* thin prisms in front of the lower half of the objective. As the telescope is moved about its horizontal axis a geared wheel rotates these two prisms in opposite senses but round the same (telescope) axis, and the image is moved accordingly. Each prism in its rotation is responsible for a lateral (or distance) displacement of the image and also a vertical displacement. The vertical displacements cancel and the lateral, together, effect a reading on the staff of $l \cos \theta$, where l is the uncorrected distance and θ the angle of elevation or depression. The Wild telemeter effects the same order of accuracy with a special fitting in the objective of the ordinary (and very remarkable) theodolite. A counterweight is added. The Wild instrument does not automatically reduce by this to the horizontal and the optical design and staff scales differ from those of the Bosshardt. Several other designs and instruments for the same general purpose are described.

The latter half of the book is devoted to errors, systems of employment, and comparison of results with "older fashioned" methods. The chapter on errors, their effect, and best antidotes, is thorough and clear. It is indispensable to a grasp of the possibilities of the method. The comparison with other methods gives cause to think. It does not follow, of course, that our conditions are similar to those of Switzerland, nor does it follow that an optical instrument designed for the atmospheric conditions of central Europe will stand up to the weather of the Hebrides or of Malaya. We shall have to watch these instruments carefully, however, and they are of the type pre-eminently suitable to the engineer.

The translation by Mr Delessert no doubt does justice to the original for the style indicates that blend of mastery and enthusiasm which is so attractive.

A book for all surveyors.

H. S. L. WINTERBOTHAM.

Handbuch der wissenschaftlichen und angewandten Photographie. Herausgegeben von ALFRED HAY. Band VII. *Photogrammetrie und Luftbildwesen*. Bearbeitet von R. HUGERSHOFF. Pp. vii + 264; 271 Figs. (Vienna: Julius Springer, 1930.) Price RM. 28, gebunden RM. 30.80.

Of the compilation of *Handbücher* there seems to be no end, but it must be admitted that the average *Handbuch* is an extremely useful book of reference. One drawback to many of these treatises is the fact that, although they contain very complete accounts of work carried out in Germany, descriptions of instruments constructed and results obtained in other countries are referred to very briefly or even entirely ignored. The present volume comes within this category, though here there may be some excuse, as the amount of information available in other countries with regard to the subject under discussion is probably small in comparison with that available in Germany and Austria.

The book is divided into nine sections. The first two are quite short and deal respectively with the historical development of photogrammetry and the fields of application and advantages of photogrammetric methods. In the third section the problems of reconstructing an object from a photograph are discussed. The fourth section deals with the point by point reconstruction of an object with the aid of a pair of photographs, both by means of separate work on each of the photographs and by means of the simultaneous examination of both by stereoscopic methods. The problem of automatic reconstruction (autogrammetry) is considered in the next section. The apparatus required for taking suitable photographs—cameras, photographic lenses, shutters, plate and film holders, etc.—are described in the sixth section, which also contains a discussion of the camera constants and their determination. The seventh section deals with the methods adopted for determining the orientation of single, double, and multiple photographs. The question of accuracy is discussed in the eighth section, while the last section deals with the various problems more especially connected with the technique of aerial survey work.

The author, who is an acknowledged expert in the subject and is the designer of quite a number of the instruments described, is to be congratulated on having compiled a book which should prove to be of great service to those who are engaged in photogrammetric work. Now that the importance of aerial survey work is growing rapidly, the appearance of such a book is welcome, as it gives an authoritative description of the apparatus and methods employed in Germany and Austria. The printing and the reproduction of the many diagrams and photographs are excellent.

Applications of Interferometry. By W. EWART WILLIAMS, M.Sc. Pp. viii + 104; 43 Figs. (London: Methuen & Co., Ltd., 1930.) Price 2*s*. 6*d*. net.

This admirable little book deals with a subject of ever-increasing importance and its appearance is therefore opportune. It consists of six chapters, in the first of which the author discusses the laws governing the interference of light and divides the methods of obtaining interference effects into two broad classes: (*a*) those which require a point source or, if the effects are required in only one direction, a line source (division of wavefront), and (*b*) those in which the beam is divided by partial reflection into two or more beams (division of amplitude). The second chapter is devoted to a discussion of the effects belonging to class (*a*) and includes descriptions of the Rayleigh interferometer, Michelson's method of measuring stellar diameters, and Gerhardt's method of measuring the angular diameters of ultramicroscopic particles; the diffraction grating is also dealt with and reference is made to the author's recent improvements in the echelon reflection grating. The effects belonging to class (*b*) are considered in Chapter III; the interference in thin films is discussed and the Jamin interferometer described. Chapter IV deals with the Michelson interferometer and its applications to metrological purposes and such problems as the detection of ether drift. In the fifth chapter the simultaneous division of amplitude and wavefront is discussed and descriptions are given of Twyman and Green's method of testing prisms and lenses and of Koster's method of determining absolute wave-lengths. The last chapter is devoted to interference effects with more than two beams, such as are obtained with the Fabry-Perot interferometer and Lummer plates. A short account is given of miscellaneous applications of multiple-reflection fringes.

The book is written in a very clear and concise manner so that even those who know little or nothing about optical interference will have no difficulty in understanding practically every word. To those who are engaged in interferometric work the chief defect of the book will prove to be its compactness. It is to be hoped that the author, who has shown himself to be a master of his subject, will proceed to the preparation of a more elaborate treatise.

Definitions and Formulae for Students (*Light and Sound*). Compiled by P. K. BOWES, M.A., B.Sc. Pp. iv + 36; 3 Figs. (London: Sir Isaac Pitman & Sons, Ltd., 1930.) Price 6*d*. net.

According to the preface, this booklet is intended to refresh the memories of students before examinations. The author has managed to condense a great deal of information into a small space, but the terseness of the definitions may in some instances lead to misunderstandings. It is quite conceivable, for example, that a student after reading "Diopter. Practical unit of focal length of lenses. A lens of one diopter has a focal length of one meter" might in an examination state that a lens of two dioptres has a focal length of two metres! A simple rewording of the definition would remedy this defect. The section dealing with optical formulae might with advantage have been introduced by a brief statement of the sign convention adopted, as so many different conventions are used by authors of optical text-books. Apart from one or two such defects, however, the booklet will, no doubt, be found to fulfil the function for which it is intended.

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PROCEEDINGS
AT THE
MEETINGS OF THE OPTICAL SOCIETY
1930–31

16th October, 1930

Meeting held at the Imperial College of Science.

Mr F. Twyman, President, in the Chair.

Elections (Membership): Dr Allan Ferguson and Mr W. D. Wright.

The following were demonstrated:

"The Vickers' Projection Microscope." By R. L. Smith, F.C.S.

"The Vickers' Pyramid Hardness Testing Machine." By Messrs Vickers-Armstrongs, Ltd.

"New Model Works Projection Microscope." By Messrs C. Baker.

"Brinell Microscope." By Messrs C. Baker.

13th November, 1930

Meeting held at the Imperial College of Science.

Mr F. Twyman, President, in the Chair.

It was announced that the Council had appointed Mr E. T. Hanson to succeed Mr A. Whitwell as Hon. Secretary (Papers) for the remainder of the session.

Reference was made to the death of Colonel J. W. Gifford.

The following paper was read:

"The Experimental Proof of a Fundamental Photo-electric Law." By N. R. Campbell.

The following were demonstrated:

"The Use of the Spectrograph in Metallurgical Analysis." By D. M. Smith, A.R.C.S., B.Sc., D.I.C.

"A New Type of Spectrophotometer." By H. Buckley, M.Sc., F.Inst.P., and F. J. C. Brookes.

11th December, 1930

Meeting held at the Imperial College of Science.

Mr F. Twyman, President, in the Chair.

Election (Membership): Mr J. O. White.

The following papers were read:

"New Knowledge of Old Telescopes." (A Supplement to the Third Paper on the Court Collection.) By Thomas H. Court and Moritz von Rohr.

"Interpolation Formulae for the Refractive Indices of Glass." By Mrs E. Gifford.

"On the Determination of the Transmission of Coloured Signal Lenses." By H. Buckley, M.Sc., F.Inst.P.

6th, 7th and 8th January, 1931

Twenty-first Annual Exhibition of Electrical, Optical and other Physical Apparatus held at the Imperial College of Science, jointly with the Physical Society.

The following discourses were given:

"Searching for Minerals with Scientific Instruments." By E. LANCASTER-JONES, B.A.
"The Physics of Sport." By Prof. Sir GILBERT WALKER, F.R.S.

12th February, 1931

Meeting held at the Imperial College of Science.

Mr F. TWYMAN, President, in the Chair.

Elections (Membership): Prof. T. L. R. AYRES and Dr N. C. ADHYA.

(Student Membership): Mr A. G. TURNER.

Messrs T. F. CONNOLLY and W. D. WRIGHT were elected to act as Hon. Auditors of the Society's accounts for the year 1930.

Reference was made to the death of the Hon. Sir Charles A. Parsons.

The following papers were read:

"Modern Optical Glass as Exemplified by the List of the Parsons Optical Glass Company dated September, 1926." By T. SMITH, M.A., F.Inst.P.

"On the Fixed Points of a Colorimetric System." By J. GUILD, A.R.C.S., F.Inst.P., F.R.A.S.

The following were demonstrated:

"The Moll Microphotometer." By Messrs ADAM HILGER, Ltd.
"The Pulfrich Photometer." By Messrs CARL ZEISS.
"The Cambridge Recording Microphotometer." By Messrs CAMBRIDGE INSTRUMENT Co., Ltd.

12th March, 1931

Meeting held at the Imperial College of Science.

Prof. A. F. C. POLLARD, Vice-President, in the Chair.

Elections (Membership): Capt. C. R. F. HOARE, Lieut. H. M. PATERSON, and Mr A. PITCHFORD.

The following papers were read:

"The Measurement of Optical Density and a Demonstration of a Photo-electric Density-meter." By F. C. TOY, D.Sc.

"The 'Tavistock' Transit Theodolite." By E. WILFRED TAYLOR.

"On Absolute Refractive Indices in Geometrical Optics." By T. SMITH, M.A., F.Inst.P.

26th March, 1931

Meeting held at the Imperial College of Science.

Mr J. GUILD, Vice-President, in the Chair.

The following papers were read:

"Secondary Conjugate Surfaces." By T. SMITH, M.A., F.Inst.P.
Graphical Constructions for a Refracted Ray." By T. SMITH, M.A., F.Inst.P.
Fused Bifocal Spectacle Lenses." By A. WHITWELL, M.A.

14th May, 1931

Annual General Meeting held at the Imperial College of Science.

Mr F. TWYMAN, President, in the Chair.

The Hon. Secretary presented the Annual Report* of the Council, which was approved.

The Hon. Treasurer presented his Report† and Balance Sheet‡, which were approved.

The Chairman read the list of persons nominated by the Council for office in the session 1931–2 and declared all these duly elected as no other nominations had been received:

President: Professor A. O. RANKINE.
Vice-Presidents: Dr J. S. ANDERSON, Mr D. BAXANDALL,
Mr E. F. FINCHAM, Professor A. F. C. POLLARD.
Hon. Secretary (Business): Mr W. B. COUTTS.
Hon. Secretary (Papers): Mr E. T. HANSON.
Hon. Treasurer: Major E. O. HENRICI.
Hon. Librarian: Dr J. J. HEDGES.
Editor of Transactions and Assistant Secretary: Dr J. J. HEDGES.

Council:

Already serving:	Elected May, 1931:
Mr W. B. BARKER.	Instructor-Captain T. Y. BAKER.
Mr T. CHAUNDY.	Mr H. H. EMSLEY.
Dr C. V. DRYSDALE.	Mr J. GUILD.
Mr S. A. EMERSON.	Professor L. C. MARTIN.
Mr W. GAMBLE.	
Dr W. M. HAMPTON.	
Mr J. W. HASSELKUS.	
Mr R. S. WHIPPLE.	

Votes of thanks to the retiring Officers and Members of Council, to the Hon. Auditors, to the Governors of the Imperial College, with Professor Thomson, for the use of the College premises for the meetings of the Society, and to Messrs Banfield, Tonks, and Shepherd for their assistance at the meetings of the Society, were unanimously passed.

14th May, 1931

Meeting held at the Imperial College of Science.

Prof. A. O. RANKINE, President, in the Chair.

Election (Membership): Mr A. F. BLAYLOCK.

The following lecture was delivered:

"Optical Experiments with Electrons." By Professor G. P. THOMSON, F.R.S.

11th June, 1931

Meeting held at the Imperial College of Science.

Prof. A. O. RANKINE, President, in the Chair.

Elections (Membership): Mr H. C. BINSTEAD and Mr J. H. L. SMITH.

The Thomas Young Oration was delivered by Sir JOHN H. PARSONS, D.Sc., F.R.C.S., F.R.S., his subject being "Young's Theory of Colour Vision (1801–1931)."

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* See p. ix. † See p. xiii. ‡ See pp. xiv, xv.

25th June, 1931

Meeting held at the Imperial College of Science.

Prof. A. O. Rankine, President, in the Chair.

The following papers were read:

"Reflection Factors of Photographic Papers." By C. Dunbar, M.Sc.

"An Application of the Photo-electric Cell to a Comparison of the Efficiencies of Photographic Shutters." By John S. Anderson, M.A., D.Sc., F.Inst.P.

The following was demonstrated:

"The Anumbra Prism Ophthalmoscope." By H. H. Emsley, B.Sc., and E. F. Fincham.

THE OPTICAL SOCIETY

REPORT OF THE COUNCIL TO THE ANNUAL GENERAL MEETING OF MEMBERS, 14TH MAY, 1931

The Council of the Optical Society presents the following Report for the year ending 31st December, 1930.

During the year the Annual General Meeting and nine Ordinary Meetings of the Society were held at the Imperial College of Science and Technology by permission of the Governors and Professor Thomson, to whom the thanks and appreciation of the Society are due.

The average attendance at the meetings was 35, which is slightly better than in 1929. During the year fifteen papers were communicated and fourteen demonstrations were given at the Ordinary Meetings. At the February Meeting members had the privilege of listening to the inspiring address delivered by their President, Mr Frank Twyman, F.R.S., on "Optics in Radio Transmission and other Fresh Fields."

At the March Meeting, Professor R. A. Sampson, Astronomer Royal for Scotland, an Honorary Fellow of the Society, communicated a paper on "The Purpose and Design of the New Equipment at the Royal Observatory in Edinburgh." This paper was followed by descriptions of the new 36-inch Reflector for Edinburgh Observatory by Mr Young, of Messrs Sir Howard Grubb, Parsons & Co., and of the new Spectrograph for use with this telescope by Mr Dowell, of Messrs Adam Hilger, Limited.

On the 4th and 5th June, in conjunction with the Physical Society, a very successful Discussion on Photo-Electric Cells was held at the Imperial College of Science and Technology. More than thirty papers were presented at the several sessions dealing with almost every aspect of the theory, use, and application of Photo-Electric Cells, and workers from various centres on the Continent and in North America attended and took an active part in the discussion. The Councils of the participating Societies arranged that all papers read, together with a full report of the Discussion, should be issued as a separate publication under the editorship of Dr J. S. Anderson. The Report was published early in September, 1930. The thanks of the Optical Society are due to Dr Anderson for the valuable services he has rendered in this connection.

The Twentieth Annual Exhibition of Optical, Electrical and other Physical Apparatus, under the auspices of the Physical and Optical Societies, was held at the Imperial College of Science and Technology on the 7th, 8th, and 9th January. This Exhibition surpassed that of 1929 with respect to the number of exhibitors and visitors. A new feature at the Twentieth Exhibition was the institution of a competition for apprentices and learners employed by exhibiting firms. The examples of craftsmanship and draughtsmanship presented by the entrants showed that individual skill of a high order, which was characteristic of the old instrument makers, is still to be found among those who are beginning to follow in their steps. The thanks of the Society are due to Dr C. V. Drysdale, Professor A. F. C. Pollard, Sir Thomas Stanton, and Mr William Taylor, who kindly undertook the laborious task of acting as judges of these exhibits.

During the Exhibition, Discourses were delivered by the Right Hon. Lord Rayleigh, M.A., Sc.D., F.R.S., on "Iridescent Colours in Nature from the Standpoint of Physical Optics," Mr S. G. Brown, F.Inst.P., F.R.S., on "Gyro-Compasses for Gun-Fire Control," and Sir Ambrose Fleming, M.A., D.Sc., F.R.S., on "Television, Present and Future."

The *Transactions*, edited during the past year by Dr J. J. Hedges, have been maintained at their customary high standard. It has been gratifying to find that there is an ever growing demand not only for current numbers but also for earlier parts. During the year it has been found necessary to reprint Volumes XV and XVI and Part 3 of Volume XIV in order to meet demands.

The Council regrets to have to record the loss of the valuable services of Mr A. Whitwell, who resigned from the office of Honorary Secretary (Papers) owing to ill-health. Mr E. T. Hanson was appointed by the Council to serve in this office until the Annual General Meeting.

The Council records with deep regret the loss by death of three Fellows of the Society, Colonel J. W. Gifford, who has enriched the pages of the *Transactions* by records of his most valuable work in several branches of Optics, Professor L. H. Cooke, and Mr J. H. Harrison.

As in former years, members of the Society have been invited to attend the Lectures on "Physics in Industry" by the Board of the Institute of Physics, and the Meetings of the Illuminating Engineering Society. Mr Whipple continued to represent the Society on the National Committee of Physics. Mr Twyman represented the Society on the Board of the Institute of Physics.

Your Council has been somewhat concerned at the comparatively small number of papers offered to the Society, and the relatively poor attendance at Ordinary Meetings. It has endeavoured, as in the past, to include interesting demonstrations in the business of the meetings whenever possible, and would ask members to assist in striving to ensure that the Society should fulfil to the utmost the purpose for which it exists. Members can render loyal service to their Society by taking such steps as they can to provide business for the meetings, by introducing new members, and by attending regularly.

MEMBERSHIP

During the year eight Members and two Students were elected. Seventeen transfers from Membership to Fellowship were made and one transfer from Studentship to Membership. Two Fellows and one Member resigned, and three Fellows and one Member died. The Membership of the Society thus shows an increase of three, the total number at 31st December, 1930, being 304, made up as follows:

Ex-officio Fellow	1
Honorary Fellows	10
Fellows	133
Members	141
Corporate Members	9
Student Members	10
Total	304

The Council invites Members to co-operate with it in strengthening the position of the Society by endeavouring to increase the membership. Application forms can be obtained from the Assistant Secretary, 1 Lowther Gardens, S.W. 7, at any time, or from the Secretaries at any Ordinary Meeting.

LIBRARY

In addition to the regular journals the following publications have been received during 1930:

Penrose's Annual, Vol. XXXIII. Edited by WILLIAM GAMBLE, F.R.P.S., F.O.S.

Oeuvres de l'Institut Dzerjinski des Ingenieurs du Transport à Moscou (in Russian), Fascicule XIV.

The Selenium Cell, its Properties and Applications. By G. B. BARNARD.

The Theory and Design of Illuminating Engineering Equipment. By L. B. W. JOLLEY, M.A., M.I.E.E., J. W. WALDRAM, B.Sc., and G. H. WILSON, B.Sc., A.M.I.E.E.

Band Spectra and Molecular Structure. By R. DE L. KRONIG.

An Introduction to Applied Optics. Vol. I. *General and Physiological*. By L. C. MARTIN, D.Sc., A.R.C.S., D.I.C.

Photo-electric Cells and their Applications. Edited by JOHN S. ANDERSON, M.A., D.Sc., F.Inst.P.

Données Numériques de Spectroscopie, Extrait du Vol. VII. Rédigées par L. BRUNINGHAUS, V. HENRI, et F. WOLFERS.

Tables Annuelles de Constantes et Données Numériques, Table des Matières des Vol. I à V. Rédigée par G. KRAVTZOFF.

Applications of Interferometry. By W. EWART WILLIAMS, M.Sc.

Definitions and Formulae for Students (*Light and Sound*). Compiled by P. K. BOWES, M.A., B.Sc.

Mesure Optique des Distances et Méthode des Co-ordonnées Polaires. Par RODOLPHE BOSSHARDT.

La Lumière Monochromatique, sa Production et son Emploi en Optique Pratique, Deuxième Édition. Par CH. FABRY.

Die optischen Instrumente, Brille, Lupe, Mikroskop, Fernrohr, Aufnahmelinse und ihnen verwandte Vorkehrungen, Vierte Auflage. Von Dr MORITZ VON ROHR.

Handbuch der Photographie, Band VII. Bearbeitet von R. HUGERSHOFF.

British Association for the Advancement of Science:

Report of the Ninety-eighth Meeting, 1930.

Department of Scientific and Industrial Research:

Illumination Research, Technical Paper, No. 8. *The Effect of Glare on the Brightness Difference Threshold.* By W. S. STILES, Ph.D.

Medical Research Council:

Reports of the Committee upon the Physiology of Vision. VII. *A Re-determination of the Trichromatic Mixture Data.* By W. D. WRIGHT.

The National Physical Laboratory:

Collected Researches, Vol. XXI.
Report for the Year 1929.

Bureau of Standards:

Research Paper No. 112. *Optical Heterogeneity of a Fused Quartz Disk.* By L. W. TILTON and A. Q. TOOL.

Miscellaneous Publication No. 115. *Annual Report of the Director for the Fiscal Year ended June* 30, 1930.

Massachusetts Institute of Technology:

Abstracts of Scientific and Technical Publications, Nos. 5 and 6.

Smithsonian Institution:

Annual Report, 1929.

TREASURER'S REPORT FOR THE YEAR 1930

The income for the year shows an increase of £38. 19*s*. 1*d*. over last year. The receipts for sales of publications have exceeded by £24. 9*s*. 9*d*. the receipts for last year, an unexpected result in view of the large increase then recorded. The subscriptions income, on the other hand, has varied but little since the subscriptions were reduced to their present level. It would be more satisfactory if the same steady increase could be recorded in the subscriptions as in the sales.

The ordinary expenses have been normal, but there have been two items of extraordinary expenditure. It was stated in the last Report that it had been decided to reprint, at a cost of £108, certain old numbers of the *Transactions* which were out of print. This amount was charged in 1930, together with the cost of reprinting a few more numbers, the total cost being £162. 7*s*. 9*d*. The second special item was the Joint Discussion with the Physical Society on "Photo-Electric Cells and their Applications." The Society's share of the cost, less receipts for sales up to the end of 1930, was £141. 0*s*. 3*d*. Both these items should result in further receipts from sales, but no credit has been taken in the accounts for the value of the stock of publications.

The net result for the year is an excess of expenditure over income of £221. 5*s*. 1*d*. and the Accumulated Funds now stand at £425. 7*s*. 4*d*.

The Discussion on "Photo-Electric Cells and their Applications" was financed by the Society, and the Physical Society's share of the cost is included in the £510. 17*s*. 1*d*. shown as Sundry Debtors in the Balance Sheet. This has now been received.

The Investments are shown "at cost" in the Balance Sheet. The market value on 31st December, 1930, was £765, representing an appreciation of £7 over the book value.

As usual the assets shown in the Balance Sheet are all (with the possible exception of subscriptions due) liquid assets, and no credit has been taken for the value of the stock of publications, books or furniture, though this is considerable, and they are insured against loss by fire for the sum of £300.

E. O. Henrici,
Hon. Treasurer.

12th March, 1931.

INCOME AND EXPENDITURE ACCOUNT FOR THE YEAR ENDED 31ST DECEMBER, 1930

1929 £ s. d.	*Dr.* EXPENDITURE	£ s. d.	£ s. d.
	To Printing and Stationery:		
444 3 2	Printing and Distributing *Transactions* . . .	539 4 11	
28 10 11½	Office Printing and Stationery	29 11 10	
			568 16 9
	Clerical Assistance:		
125 0 0	Institute of Physics (includes administration of Exhibition) . .	125 0 0	
48 14 2	Editorial Expenses . .	50 10 6	
28 18 7	Other Expenses . .	15 9 9	
			191 0 3
	Reproducing rare parts of *Transactions* . .		162 7 9
	Printing and Publishing "Photo-Electric Cells and their Applications"	519 10 5	
	Less Amount due from Physical Society . . .	378 10 2	
			141 0 3
39 13 9½	Postage and Receipt Stamps		43 12 3
15 16 3½	Expenses at Meetings		16 4 9
	Printing List of Members		14 14 0
5 0 11	Sundry Expenses		8 4 9
10 0 0	Advertising		4 16 0
144 14 8½	Balance, being excess of Income over Expenditure, transferred to Accumulated Fund		—
£890 12 7			£1150 16 9

1929 £ s. d.	INCOME *Cr.*	£ s. d.	£ s. d.	£ s. d.
	By Subscriptions:			
246 14 3	Fellows		263 9 11	
158 11 0	Members		152 14 11	
31 10 0	Corporate Members . .		28 7 0	
3 3 0	Student Members . .		3 3 0	
439 18 3			447 14 10	
	Less:			
	Rebate to members of the Institute of Physics	12 1 6		
	Subscriptions written off	—		
18 7 4			12 1 6	
421 10 11				435 13 4
42 15 6	Advertisements in *Transactions*, *less* expenses			45 19 7
332 16 1	Sales of Publications			357 5 10
37 7 10	Interest and Dividends			37 15 2
56 2 3	Physical Society—Exhibition Account .			52 17 9
	Balance, being excess of Expenditure over Income, transferred to Accumulated Fund			221 5 1
£890 12 7				£1150 16 9

OPTICAL CONVENTION, 1926. TRUST ACCOUNT

	£	s.	d.
To Stationery	2	2	6
Balance carried forward	137	1	3
	£139	3	9

	£	s.	d.
By Balance brought forward from 1929	122	2	9
Sales of Publications	12	1	0
Dividends from Investment	5	0	0
	£139	3	9
By Balance brought forward	137	1	3

BALANCE SHEET AT 31ST DECEMBER, 1930

LIABILITIES

	£	s.	d.	£	s.	d.
Sundry Creditors				1258	0	1
Accumulated Funds	646	12	5			
Less Balance of Income and Expenditure Account	221	5	1			
				425	7	4
Life Compositions Account:						
Balance at 31st Dec., 1929				94	10	0
Subscriptions received in advance				4	4	0
Optical Convention, 1926, Trust Account				137	1	3
				£1919	2	8

ASSETS

	£	s.	d.	£	s.	d.
Sundry Debtors				510	17	1
Subscriptions Due				15	15	0
Investment:						
£750 5% War Loan (at cost)				758	14	9
Cash at Bank: Deposit Account	350	0	0			
Current Account	274	8	9			
Cash in hand	9	7	1			
				633	15	10
				£1919	2	8

E. O. HENRICI,
Hon. Treasurer.

We have audited the above Balance Sheet and have obtained all the information and explanations we have required. We have verified the Bank Balances and the Investment. In our opinion such Balance Sheet is properly drawn up so as to exhibit a true and correct view of the state of the Society's affairs according to the best of our information and the explanations given to us and as shown by the books of the Society.

Knox, Cropper & Co.
Chartered Accountants.

Spencer House,
South Place, E.C. 2.
16*th March*, 1931.

Examined and approved on behalf of the Society.

T. F. Connolly,
W. D. Wright,
Hon. Auditors.

27*th May*, 1931.